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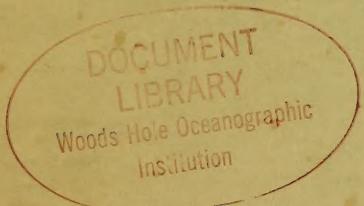
SPECIAL PUBLICATION

OCEANOGRAPHIC INSTRUMENTATION

FINAL REPORT OF THE COMMITTEE  
ON INSTRUMENTATION

Second Edition

OCTOBER 1960



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## FOREWORD

The U. S. Navy Hydrographic Office in the conduct of its ocean survey program has become one of the largest users of equipment and instruments required to carry out this work. More than two years ago it became evident that a comprehensive study was needed to assess the available instrumentation and recommend a future course of action that would insure the rapid acquisition, processing, and storage of accurate marine environmental data. Accordingly, in March 1958, a Committee on Instrumentation was formed within the U. S. Navy Hydrographic Office to conduct the study and report its findings. The Committee issued its report in the summer of 1959. The report was intended solely for "in-house" use and guidance. However, word of the report spread and the limited supply of available copies was soon exhausted. Interest in the report indicated that wide distribution would be very worthwhile.

This present edition is a revision of the earlier report to make it more suitable for external distribution. Although it was the Committee's intention to be comprehensive, no claim is made that the report represents an exhaustive study. Some equipments or instruments have undoubtedly been overlooked. For others, improvements or new developments may have been made in the past year that are not incorporated in the report. Similarly, references when cited in the various sections are not intended to be all inclusive.

In conclusion, it is not the intent or purpose of this report, by inclusion or omission, by favorable or unfavorable comment, to recommend or degrade any one instrument or system with respect to another. Rather it is hoped that this report will serve as a stimulus to focus attention on, and remedy some of the deficiencies in, the entire field of marine geophysical instrumentation. Comments which may either improve or correct this report are invited.

*E. C. Stephan*  
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Hydrographer





## PREFACE

This is the final report of the Hydrographic Office Committee on Instrumentation. Two previous reports (progress reports) are included as Appendixes A and B. This report is composed of sections prepared by several people. Credit has been given for authorship wherever possible. Members of the Committee on Instrumentation assisted in the preparation of Sections II through XVI; Section I was prepared exclusively by the Committee. Various Divisions of the Hydrographic Office were consulted from time to time and asked to contribute information and recommendations. By virtue of this wide participation, it is believed that this report is more representative of Office-wide views than it otherwise would have been.

An effort was made by the Committee to establish accuracy limits for the various measurements required. However, because of the diversity of applications for each type of data, and the practical willingness of users to trade accuracy for economy, simplicity, and other advantages, this was possible only in a limited way.

It is the intent of the Hydrographic Office to review annually developments in marine geophysical instrumentation and to summarize significant accomplishments in annual supplements to this report.

In addition to the present members of the Committee, who participated in the preparation of this report and who are listed below, LCDR R. Plunkett and Mr. R. Fisk were members during the early phases of the Committee's work. Mr. T. J. Wehe coordinated the revision and preparation for printing of the second edition of this report.

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## TABLE OF CONTENTS

	<i>Page</i>
FOREWORD	i
PREFACE	iii
LIST OF FIGURES	vii
LIST OF TABLES	vii
I. Summary of Conclusions and Recommendations	I-1
II. Geophysical Data Collection System	II-1
III. Sea water Temperature Measurements	III-1
IV. Salinity and Density Measurements	IV-1
V. Pressure (Depth) Measurements	V-1
VI. Currents Measurements	VI-1
VII. Ocean Wave Measurements	VII-1
VIII. Radiation Measurements	VIII-1
IX. Marine Biological Sampling	IX-1
X. Bottom Material and Strata Determinations	X-1
XI. Bathymetric Measurements	XI-1
XII. Tide Measurements	XII-1
XIII. Gravity Measurements	XIII-1
XIV. Geomagnetic Measurements	XIV-1
XV. Positioning	XV-1
XVI. Winches and Hoists	XVI-1
Appendix A. First Progress Report	A-1
Appendix B. Second Progress Report	B-1
Appendix C. Description of an Oceanographic Data System for Submarines	C-1
Appendix D. Tabulation and Summary of Continuous-Profile Systems	D-1
Appendix E. Instrumentation Summary	E-1



## LIST OF FIGURES

II-1. Shipboard Geophysical Data Recording System	II-2
II-2. Auxiliary Data Recorder	II-3
II-3. Record and Playback Circuits	II-5
VII-1. Wiancko Pressure Measuring System	VII-5
VII-2. Shorebased Recorder of Low-Frequency Ocean Waves	VII-8
VII-3. Resistance Wire Wave Staff	VII-15
C-1. Mode 1 (Routine) for Digital Oceanographic Data System	C-2
C-2. Mode 2 (Diving) for Digital Oceanographic Data System	C-4
C-3. Mode 3 (Hovering) for Digital Oceanographic Data System	C-6
C-4. Submarine Oceanographic Data Console	C-8
C-5. Housing for Sensing Elements for Digital Oceanographic Data System	C-10

## LIST OF TABLES

VI-1. Comparison of Prices, Depth Limits and Speed Ranges of Various Current Instruments	VI-5
B-1. Summary of Comments from Instrumentation Questionnaires	B-15
D-1. Summary and Comparison of Features of Continuous-Profile Equipment	D-13



## I. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

### Committee on Instrumentation

#### A. INTRODUCTION

Historically the Hydrographic Office has interpreted its mission as primarily that of performing surveys with equipment available commercially or from other agencies. Consequently, in the past this Office has looked to others for leadership in the development of survey instruments. The establishment of the Instrumentation Division and, more recently, the Committee on Instrumentation resulted from the recognition that instruments available through these channels are not always adequate and that the Hydrographic Office must provide more of the leadership for the development of oceanographic and other marine geophysical instruments.

It has been suggested informally that the Hydrographic Office should act as the material bureau for geophysical instrumentation for the Navy. The Committee does not feel that it is within its purview to comment on such a suggestion. However, it does seem evident that this Office must play a dominant role in the development of geophysical instruments to meet peculiar Navy requirements, most of which concern surveys conducted by the Hydrographic Office. With the recent publicity given to oceanography, numerous corporations have submitted proposals for development of oceanographic instruments. To evaluate these proposals properly and to give mature guidance for the expenditure of such funds as might be made available for this purpose, the Hydrographic Office must have greater firsthand experience in the development, calibration, use, and maintenance, of a variety of instruments. The value of this firsthand experience cannot be overemphasized; lack thereof results in mistakes, indecision, and instability in long-range plans. Facilities not now available at the Hydrographic Office will be required and inevitably will entail funding at a level not heretofore provided for this purpose.

#### B. POLICIES AND PROCEDURES

The three major problem areas of instrumentation are: (1) design and development, (2) test and evaluation, and (3) maintenance.

The first of these, design and development, demands the use of all of the ingenuity available within an organization, if it is to be productive. The second, test and evaluation, requires adequate central facilities, a competent staff, and the development of standard techniques.

This often-slighted function cannot be overemphasized in importance in geophysical work. The last, maintenance, is a joint problem for a centralized facility and field personnel properly trained in the operation and maintenance of equipment.

If full advantage is to be taken of the potential for improvement of measurement and analysis techniques that exists within the Office, greater opportunity must be made for the exploration and development of instrumentation ideas generated by employees of the Office. Usually these ideas result from recognition of a need and are accompanied by a strong, creative motive. It is difficult to transfer the ideas to others for further development and almost impossible to convey the essential motivation. How to obtain the advantages of centralized facilities and skills without obstructing initiative and creativity is a problem that confronts every technical organization.

A pattern is evident within established, progressive organizations: Generally, after a period of experimentation with different degrees of centralization, laboratories establish centralized facilities for engineering new instruments or components, calibrating and testing instruments, preparing drawings and specifications, and for providing related consultation and other services, but retain throughout the organization appropriate laboratory space and facilities for the exploration and initial development of ideas and for testing and becoming acquainted with components.

In most scientific work the selection, modification, maintenance, and use of instrumentation are so intimately tied to the rest of the work that separation of these responsibilities inevitably dilutes the effectiveness of the overall scientific effort. On the other hand, very often the investigating scientist has neither the capability nor the time to conduct full-time instrument development. In the Hydrographic Office, as in other organizations, ideas for improvements originate in both the scientific units and the engineering units. Avenues for developing these ideas include the following: (1) by the originating investigator, (2) by the originating instrumentation engineer, (3) by the scientist assisted by an instrument technician or engineer, (4) by the engineer with access to consultation with scientist users, and (5) by private firms under contracts originated and monitored by the originating scientific unit or by the instrumentation component.

It is the recommendation of this Committee, after considerable study and discussion, that use of all of these avenues for improvement of the technical capabilities of this Office be encouraged, and that it be left to management decision, with advice from the Director, Instru-

mentation Division, as to which is most appropriate in each case that arises.

Detailed results of all instrument calibrations should be forwarded routinely to the primary user of the instrument. In addition, a permanent record should be kept by the Instrumentation Division of this Office of the performance and calibration results of each instrument and should be available to anyone upon proper request. Such a record is now kept on each BT grid held by this Office. This provides ready information on the instrument for evaluating results and recommending recalibration or disposal. Maintenance of such a record for all instruments would require a form to be sent out and returned with each instrument for collecting needed information on its condition upon arrival in the field, difficulties encountered in its use, modifications made to it, etc. More details on the requirements for proper test and evaluation of instruments are contained in the following section on facilities.

The program of training scientific personnel in the proper use and maintenance of instruments, which was initiated two years ago, should be expanded and improved. This program should be worked out jointly by the operating divisions, the Instrumentation Division, and the Training Branch.

To give further confidence in formulating long-range plans for systems development, close liaison with leading individuals in developing oceanographic instrumentation and related systems is needed. In furtherance of this, it is recommended that three or four of the leaders in this field be invited to spend several days at the Hydrographic Office as a working group to review conclusions of this Committee and explore on a broader base means of achieving an oceanographic data collection system which would meet the common requirements of all oceanographic laboratories.

It is believed that the exchange of information and ideas through the Committee on Instrumentation has been of considerable value to the participants and consequently to the Divisions involved. For this purpose, and to give continuing guidance in this important area, it is recommended that a standing committee on instrumentation be appointed at the termination of this Committee. Such a committee should be comprised of individuals with a genuine interest in instrumentation and should meet regularly, either monthly or every second month, and otherwise as necessary.

## C. FACILITIES

One of the critical needs of the Hydrographic Office in developing and more effectively using geophysical instruments of all kinds is improved calibration facilities and the development of standards and procedures for calibrating, evaluating, and field checking all instruments. Evaluation should include determination of the probable error of measurements for each class of instruments through repeated calibration runs, field tests, and application of sampling and other statistical techniques. Two major facilities are badly needed: (1) a towing tank for use in calibrating and evaluating the numerous current meters used by the Office, and (2) a pressure-temperature calibration facility of much greater capacity and flexibility.

It is the recommendations of the Committee that steps be taken to provide these facilities and other related facilities required in the test and calibration of instruments as soon as possible.

The need for a field facility located near the water has been discussed widely within the Office. Several interim arrangements have been tried or suggested for meeting requirements for field testing instruments. The Committee recommends that a sustained effort be made to obtain a small boat, docking facilities, and a small warehouse for field maintenance and storage. Such a facility should be within 100 miles of Washington and should be easily accessible by road. In addition to Annapolis and Patuxent, which have been considered previously, the possibility of locating such a facility at the NRL Chesapeake Bay Annex should be investigated. This has a small dock and limited shop facilities and is less than 40 miles from the Hydrographic Office. It is recommended that these and other possibilities be explored and that necessary steps be taken to provide such a facility.

## D. GEOPHYSICAL DATA COLLECTION SYSTEM

Appendix A of this report discusses systems concepts and concludes that magnetic tape as a recording medium offers real advantage in flexibility, an essential feature at this stage of development of a system for oceanographic and other geophysical data collection. As is pointed out in Appendix A, a system based on generation of FM signals at the source offers advantages in that such signals are less subject to transmission loss. They can be relayed acoustically or by a single conducting cable using sea water as the return or, between surface points, by radio. Conversion to digital form is simple, and such signals are less subject to distortion with age than are analog voltages, if a control frequency

also is recorded, as is suggested. This system is treated briefly in Section II.

FM transducers already exist; however, they are rather complex and somewhat unstable. Although they appear to be superior in many respects, extensive engineering and testing will be needed to provide the reliability required. In the meantime, less sophisticated transducers can be employed in such a system by converting voltage output to frequency prior to recording. Standard, moderately priced components are available commercially for this use. Some of these components have been used successfully by the Office for recording on magnetic tape.

It is the recommendation of the Committee that continued development and testing of this system be supported with the necessary funds and be given a high priority.

This system will require some modest development or modification of transducers. It is believed that the following measurements can most readily be incorporated into such a system: (1) temperature, (2) depth (pressure), (3) salinity, with sufficient accuracy for use in coastal waters only, (4) light attenuation, (5) currents, with some further development, and (6) sound velocity.

After extensive field testing of such a limited system, which should require about six months, the Hydrographic Office should begin to instrument one of its survey vessels for more extensive collection of geophysical (oceanographic, bathymetric, etc.) data. Recording should be centralized and as automatic as the state of the art permits. The objective would be to further develop and field test a prototype of a comprehensive data collection system and to gain experience for directing its continued improvement. The Hydrographic Office is already gaining valuable practical experience along this line in its instrumentation of a submarine for oceanographic measurements. (See Appendix C.) This experience should next be applied to the broader problem of equipping a surface survey vessel for more extensive geophysical measurements meeting survey specifications.

Improvement and extension of this system for other measurements, and incorporation of more sophisticated techniques of measurement, relay, and recording of data, should be continuing objectives of the Office. It is in furtherance of this long-range objective that consultation and continued liaison with key individuals in the field of oceanographic instrumentation and related fields is proposed.

Various methods now exist for converting original data to a medium suitable for direct input into data processing equipment: (1) keypunching of EAM cards from original source documents, (2) converting punched paper tape to punched cards, (3) direct punching of paper tape, (4) use of off-line computer equipment such as punched card-to-magnetic-tape converters or magnetic tape-to-line print-out, (5) use of universal data translators to convert analog or digital magnetic tape to other digital magnetic tape, (6) use of special purpose translator devices, and (7) use of an electronic computer as a data medium translator for card-to-magnetic-tape or magnetic tape-to-line print-out. This last method is usually very costly; however, some computers (e.g. intermediate class) can do this economically on an extra shift rental basis.

For the present, the problem is reduced to that of either recording all data on punched cards or tape, or of providing a suitable means of converting from the form of the original record to punched cards or tape. For many purposes, punched cards will be the best means for tabulating or computing data; for other purposes, these will have to be converted to computer magnetic tape. During the past few years a number of instruments have been developed that can relatively inexpensively convert analog data to digital data, either coded or uncoded. A typical example of how this could be accomplished with Hydrographic Office data is described below.

Assume that sea temperature information is recorded on magnetic tape in terms of a varying audio frequency. When this magnetic tape is played back through a digital frequency counter with a ten-line output, and the output of up to five decimal digits is scanned with a scanner-coupler connected to a card punch, the temperature information will be digitally punched in terms of frequency or in terms of degrees, if the calibration is computed into the system.

The foregoing example is a relatively simple one. However, a number of other instruments are available that will allow d.c. sensing elements to enter this same system. Scanner-couplers can be modified to scan up to six six-digit counters and can be coupled to a card punch, paper tape punch, or printer in various codes. These modifications typically cost a few hundred dollars each.

#### E. SEA WATER TEMPERATURE MEASUREMENTS

No other instrumental oceanographic measurements are so widely taken as those of sea temperature. Although efforts are made to control the accuracy of these observations by screening them prior to their incorporation into data files, accuracy is far below that desired.

Three major problem areas, not all concerned with instrumentation alone, exist: (1) surface temperature observations from fleet and commercial ships, (2) bathythermograph data from fleet and other vessels, and (3) temperature-depth measurements from survey and research ships.

It appears that improvements in the accuracy of surface temperatures collected by commercial and fleet ships will have to be achieved through better instructions and more careful screening of incoming data. However, these can never be regarded as sources of precise data. Development of an inexpensive recording thermometer (along the lines of the thermitow, but hull-mounted) for installation on such ships would greatly improve the potential for accurate temperature data from these sources. If this potential is to be fully exploited, such installations will have to be accompanied by a program of instruction and continuing review.

Steps have been and are being taken to improve the quality of bathythermograms through the issuance of better instructions, development of better bucket thermometers, more frequent calibration of instruments, improved slide blanks, and better screening and processing techniques. However, it is the conclusion of this Committee that the most marked advances can be made in the collection of accurate temperature data at the present time by careful production engineering and development of one of the several electronic bathythermographs. The first objective of such development would be to make available, through normal channels, a standard, easily maintained, shallow-water instrument. Once perfected, such an instrument could be modified for deeper work and combined with manually triggered sample bottles for making complete oceanographic stations. A longer range objective is to make such an instrument sufficiently reliable and rugged that it could replace the BT for fleet use.

Although several versions of an electronic bathythermograph have been tested and evaluated by the Hydrographic Office, none has proven satisfactory for survey operations. However, each development provided certain valuable characteristics. It is, therefore, recommended that the laboratory and field testing of these instruments continue and that steps be taken to find an organization able and willing to further engineer, package, and fabricate several instruments made up of the best features of the earlier developments.

It is also recommended that the Instrumentation Division of this Office select one of the simpler designs of temperature sensors, preferably a thermistor-type, for fabrication in limited numbers for

use in the proposed geophysical data collection system and to meet other interim requirements for continuous temperature measurements.

#### F. SALINITY MEASUREMENTS

It is the conclusion of the Committee that development of a satisfactory in situ salinometer for deep water oceanography is not in prospect for the immediate future. Therefore, it is felt that some effort should be devoted toward reducing the size of, and otherwise improving, the conductivity bridge for shipboard use and possible use on submarines. The compact, high-performance salinometer developed by the Australians should be thoroughly tested and compared with other available salinometers.

A possible means for speeding up the collection of water samples was suggested in the second progress report of this Committee (Appendix B). This suggestion was for precise triggering of a multiple sea sampler at standard depths as indicated by a vibrating wire transducer or other good depth element. Triggering can be done either automatically, or manually when the proper depth is indicated by a depth recorder. By coupling this with an accurate temperature element, further speed-up could be achieved. After a satisfactory depth element has been obtained and accepted for field use, a prototype of this system should be built.

The use of interferometers and beta absorption techniques for salinity determinations should be explored further, and development of the Induction Conductivity Indicator for use in coastal waters should be continued. Additional information should be obtained on the in situ salinometers developed in West Germany for the University of Kiel, and the possibility and advisability of purchasing one of these instruments should be explored.

#### G. PRESSURE (DEPTH) MEASUREMENTS

It is difficult to draw any definite conclusions concerning the accuracies of various depth gauges because of the lack of adequate facilities for running comparative tests. Inasmuch as the measurement of depth is an essential part of nearly all oceanographic determinations, selections from existing devices must be made. On the basis of such evidence as exists, the vibrating wire transducer appears to give the most dependable measurements of depth, both in shallow and deep water. However, it is slightly higher in cost and somewhat more complex than other available instruments. The greatest area of doubt concerning the accuracy of this instrument is in establishing the effect of

changing temperature on the electronic circuitry. A provisional method for doing this by determining the time constant has been discussed with the Instrumentation Division of this Office.

It is recommended that the proposed calibration facility include provisions for rapidly testing such devices over the range of temperatures and pressures encountered in normal oceanographic work.

It also has been recommended that the Instrumentation Division conduct an evaluation test of strain gauges for pressure measurements, an application for which no specific information was available to the Committee. (Strain gauges have, however, been used in recording harbor surge.)

Because of their simplicity, Bourdon tubes probably will be used in shallow depth determinations for some time, despite their questionable accuracy. Recent field tests of these were inconclusive.

The sonar pinger system should be evaluated for Hydrographic Office use.

#### H. CURRENT MEASUREMENTS

Although it lacks many desirable features, the Roberts Current Meter is the instrument most depended upon by the Hydrographic Office for measuring ocean currents. Steps have been taken to improve its accuracy, lower its threshold speed, and simplify the data record. However, even with such improvements, the Roberts Meter cannot be regarded as a totally satisfactory general purpose current meter.

Recent developments which are currently under test by the Hydrographic Office include: (1) the adaptation of the electromagnetic log to measure currents, (2) an instrument employing two-way doppler as the basis for measuring water flow, and (3) the Snodgrass meter, which employs an extremely sensitive Savonius rotor and generates an FM signal.

The use of simple strain gauges for deriving current speeds from forces exerted on spheres or flat plates appears to be very promising. Crude models of such instruments have been assembled and tested by the Hydrographic Office with encouraging results. Because of the encouraging prospects indicated at modest cost, it is recommended that this work be continued within this Office to prove further the soundness of the concept and that a contract then be let for the con-

struction of a limited number of these instruments for field tests. The versatility of such simple devices in studying turbulence, frictional effects, and periodic variations in currents is immediately apparent. The use of hot thermistors or resistance wires in measuring currents also is promising in concept. The cost of experimental models and tests of such devices would be modest. It is recommended that current sensing elements employing thermistors or resistance wires be constructed and tested and that a decision as to further work be based on the results of these tests.

## I. OCEAN WAVE MEASUREMENTS

The Hydrographic Office has pioneered methods for measuring waves in deep water. However, its experience in measuring waves in shallow water by means of pressure transducers has been limited largely to the Wiancko system and the NOL acoustic system.

An inverted, narrow-beam echo-sounder used from a submarine produces the most accurate record of deepwater waves. However, the difficulty in obtaining submarines for the purpose limits the practical usefulness of this method. Until other satisfactory means are developed for recording ocean waves in deep water, full advantage should be taken of opportunities to obtain wave records from submarines.

None of the other deepwater devices are completely satisfactory. The earliest of these, the floating electric wave staff developed by this Office, is cumbersome and unstable. Experimentation by this Office with the accelerometer wave staff has been only partly successful. The shipborne wave recorder of the National Institute of Oceanography, which employs a pressure transducer, has been used extensively by others. Its greatest disadvantage is its uncertain response to wave periods less than about seven seconds. Evaluation of the telemetering wave buoy (splashnik) developed by the David Taylor Model Basin is still inconclusive. Certain limitations are evident, however, and it cannot at this time be regarded as a fully adequate deepwater wave instrument.

Use of an accelerometer as an integral component offers the greatest promise for deepwater wave measurements from surface ships. However, its use with either a pressure transducer (NIO) or a wave staff (H. O.) is probably not the best combination. Either a high-frequency sonic device or a radar-type instrument for measuring the distance from the prow of a ship to the water directly beneath appears to be the most promising arrangement for fully utilizing the accelerometer for wave measurements. The former seems more

practical at present and is being explored by this Office.

It is recommended that proposals for such a development be invited and, if bids are within the funding capability of the Hydrographic Office, that contracts be let; otherwise, the Office of Naval Research should be requested to sponsor the development of this instrument.

Although the Wiancko pressure measuring system has been satisfactory for the limited application to which it has been put by the Hydrographic Office, it does not appear at present to be sufficiently dependable for obtaining wave records over a period of several months, which is the most pressing requirement of this Office in inshore areas. The NOL acoustic system which appears to be better suited for this purpose is being tested by the Hydrographic Office.

It is recommended that the possible application of a vibrating wire transducer for wave measurements be explored.

Better equipment for analysis of wave records for power spectra, wave form, etc. must be obtained. Present equipment is slow and limited in application. One wave analyzer similar to that used in the David Taylor Model Basin seakeeping data analysis center (SEADAC) has been purchased to facilitate the analysis of wave and ship motion data at the Hydrographic Office. Although this analyzer is not yet operational, it is expected that the system will allow more rapid processing of this type of data.

An airborne wave recorder is highly desirable. However, extensive testing of existing instruments and exploration of suggested techniques have not been promising and indicate that development of such an instrument is probably beyond the present financial capabilities of this Office. As has been previously suggested, the Hydrographic Office probably should look to development of such an instrument by the Bureau of Naval Weapons for operational use on seaplanes.

It is recommended that all wave records be made on magnetic tape for ease in processing and be supplemented by a visual record for monitoring and other special purposes.

#### J. RADIATION MEASUREMENTS

Before confident recommendations can be made concerning radiation instruments pertinent to the work of the Hydrographic Office, considerably more experience must be gained in the use of equipment already

available through commercial sources. This is particularly true with regard to equipment for measuring long wave atmospheric and back radiation and the extinction of light in oceanic water.

The water clarity meter (photocell type) shows considerable promise for transparency and visibility measurements in coastal waters. However, continued collection and analysis of data shows that further engineering is needed to obtain greater dependability and operational simplicity from this instrument.

Early fabrication of a photometer to be used as part of the proposed geophysical data collection system is recommended.

#### K. MARINE BIOLOGICAL SAMPLING

Equipment available for marine biological sampling appears adequate to meet present requirements of the Hydrographic Office. With increased experience and added requirements, improvements in instruments probably will be required.

#### L. BOTTOM MATERIAL AND STRATA DETERMINATIONS

Emphasis in the past has been on coring equipment designed to take long cores of relatively small diameter. Larger diameter, less distorted cores are needed for engineering tests now required by the Navy. Experimental use of coring equipment modified to meet these requirements is being made by the Hydrographic Office. Development is being planned for certain in situ measurements which appear necessary to completely eliminate disturbance effects induced by coring.

Extensive inquiry has been made into the relative merits of instruments which have been used to determine sediment thickness and structure by means of essentially continuous-profile seismic reflection techniques. Some of these instruments are still under development or modification. Evidence to date indicates that of the existing devices the Seismic Profiler of the Woods Hole Oceanographic Institution and the Subbottom Depth Recorder of the Lamont Geological Observatory are best suited to Hydrographic Office requirements when used with the Precision Graphic Recorder. Since these systems are self-contained and portable, they have the added advantages that they may be easily shifted from ship to ship as need directs and that they are easily serviced. It is recommended that one of these systems be acquired and tested by the Hydrographic Office.

## M. BATHYMETRIC MEASUREMENTS

Echo sounders used by the Hydrographic Office have been developed in the past primarily for fleet use. Thus, they have not been designed to meet peculiar survey requirements. Most echo sounders lack the resolution and depth capabilities desirable for efficient survey work in deep water. Instruments of greater capability for deepwater work have been developed by the Woods Hole Oceanographic Institution and the Lamont Geological Observatory for their own use. The main feature of such instruments is a recorder, either the Precision Depth Recorder or the Precision Graphic Recorder, which allows selection from a wide range of depths at constant scale. Installation of Precision Depth Recorders aboard Hydrographic Office survey vessels has been a major improvement. The following are recommendations for further longer-range improvements:

1. Development of a means for combining on punched tape or cards the depth with positioning information and other geophysical measurements is recommended. Lamont Geological Observatory has successfully recorded course, speed, and some geophysical measurements on one graphic recorder. However, the greatest economy in the processing of survey data will come from automatic processing of such data, which should begin at the collection stage with the recording of data directly on punched tape or cards.
2. It is recommended that a stabilized, narrow beam transducer, which will eliminate hyperbolae, side echoes, etc., be developed for detailed surveys.
3. An underwater contouring system consisting of multiple transducers would increase the capabilities of survey ships by broadening the strip of bottom delineations with each passage of the ship. Not only would this decrease the time required for surveying a given area, but it also would give details of features not easily obtained with existing equipment.

The Hydrographic Office has initiated a development characteristic for the development of such a system. Current indications are that the Navy intends to proceed actively on this system. It is recommended that this Office continue to support and encourage this work.

## N. TIDE MEASUREMENTS

The portable tide gauges currently in use by this Office are generally satisfactory; however, development of pressure gauges for tidal

measurements should be followed closely for possible advantages in simplicity and versatility in operation. Development of means for telemetering information directly to a ship or other central location is desirable.

## O. GRAVITY MEASUREMENTS

The most pressing requirements for more accurate gravity surveys at sea are: (1) a calibration range off the Atlantic Coast and (2) a small portable land instrument for measuring absolute gravity to an accuracy of  $\pm 0.1$  milligal or less.

Marine gravimeters should be improved and miniaturized for more continuous use aboard surface ships as well as submarines. Because of its primary interest in marine gravity surveys, the Hydrographic Office should evaluate, or participate in the evaluation of, new marine gravimeters developed or considered for Navy use. Progress on development of a practical airborne gravimeter should be followed closely by this Office for possible future use of such an instrument aboard Project MAGNET or other aircraft. Means should be provided for incorporating gravity measurements in any geophysical data collection system developed by the Hydrographic Office.

## P. GEOMAGNETIC MEASUREMENTS

To meet requirements for small-scale isomagnetic charts, the instrumentation for airborne geomagnetic surveys can be considered reliable and accurate. Some improvements in reliability, efficiency, and flexibility could be achieved by: (1) development of a low drift voltage standard and a precise current control system for the Vector Airborne Magnetometer, (2) improvement of the mounting for the VAM detector, (3) automation of the recording system, and (4) development of a portable recording magnetometer.

Also, the Hydrographic Office should support development of improved vector and total field magnetometers to meet future requirements.

## Q. POSITIONING

More accurate long-range positioning equipment is a continuing requirement. A problem requiring immediate attention is that of determination of correction factors to be applied to positions obtained by existing radio positioning systems operating over different surfaces and under different atmospheric conditions. Automatic incorporation

of position in the record of many of the geophysical parameters is highly desirable.

The Hydrographic Office has an additional requirement for a self-contained airborne navigation and positioning system of world-wide capability.

This Office has a requirement for an accurate ranging instrument for use from ship to ship or ship to buoys over distances of 50 feet to 10 miles. The prototype of an instrument that appears to meet this requirement has been developed by the Diamond Ordnance Fuse Laboratory. The Bureau of Ships should be encouraged to obtain one of these instruments for further field evaluation by this Office.

The Hydrographic Office should follow closely developments in the application of satellites and rockets to positioning and participate in developmental projects as opportunities arise.

#### R. WINCHES AND HOISTS

The Hydrographic Office has a requirement for oceanographic winches which can be readily put aboard ships for short periods to meet special survey requirements. The most frequent requirement is for one with a relatively small drum capacity of about 5,000 feet of 3/32 inch wire. However, requirements also exist for one with a capacity of about 15,000 feet of 5/32 inch wire.

The development and field evaluation of a suitable electrical cable reel should be given a high priority. The immediate requirement is for a reel with a capacity of 6,000 feet of 0.3 inch three-conductor wire or 2,500 feet of 0.5 inch eight-conductor wire. It should be designed with ten slip rings to provide a margin for failures and to allow future use of cables with as many as ten conductors for simultaneous measurements of several oceanographic factors. A longer range requirement is for a cable reel with the much greater capacity of about 10,000 feet of 0.4 inch eight-conductor wire and as many as ten slip rings.

Requirements for deep-sea anchoring winches will vary with each type of ship and should be made known when construction or modification of ships for oceanographic work is planned.

## S. SUMMARY

The field of marine geophysics has not, in the past, had sufficient emphasis and funding to apply the modern-day state of the art to many of its instrumentation requirements. The increasing importance of oceanography, hydrography, and other marine sciences results in an acute need for sophisticated, reliable, and rugged instrumentation. The conclusions and recommendations of this report represent a first attempt to give some direction to the traditionally spasmodic development of marine geophysical instrumentation.

It is the hope of this Committee that an orderly development of instrument systems and components, with proper emphasis on engineering for accuracy and reliability, will be funded. Such a program is the only way in which "tools" for the widespread, meaningful exploration of the sea will be made readily available.

## II. GEOPHYSICAL DATA COLLECTION SYSTEM

Gilbert Jaffe

### A. INTRODUCTION

The requirement for a unified system for collecting geophysical data at sea is such that the resultant instrumentation must be capable of producing a nearly continuous analog record of each variable measured. The system must provide a relatively easy method of annotating the data collected and must lend itself either directly or indirectly to automatic data processing methods. In addition, in order to be of maximum benefit to other interested activities the system must provide an output from which data can be extracted in a form suitable for analysis by relatively simple means.

### B. THE SYSTEM

#### 1. Collection and Recording

Since the advantages of audio frequency modulation have been discussed in a previous committee report (Appendix A), they will not be covered further in this report other than to confirm the versatility and desirability of employing audio frequency as the telemetered signal. The basic block diagram for a prototype system for shipboard geophysical data collection is contained in Figure II-1. It is assumed that most transducers will lend themselves to audio frequency conversion. The transducers then would be the plug-in type and selected for a particular measurement. The connector would be a type which is completely waterproof and yet allows quick disconnection. The signal would be transmitted along an electrical cable to either a slip-ring or stationary drum-type winch. From the winch, the signal would be recorded on magnetic tape and simultaneously, but sequentially, annotated. An electronic counter would provide for monitoring the record, and the printer would make a permanent record of the monitored signal. Auxilliary monitoring equipment could be provided as required.

#### 2. Auxilliary Data Annotation

In order to provide a relatively easy means of annotating the data collected, an electronic gate would be used to impress on the magnetic tape a fixed number of cycles, from a crystal oscillator, which would be proportional to digits 0 through 9. In this way unlimited auxilliary information such as cruise number, position, time, etc. could be annotated in a fashion which is compatible with the basic system.

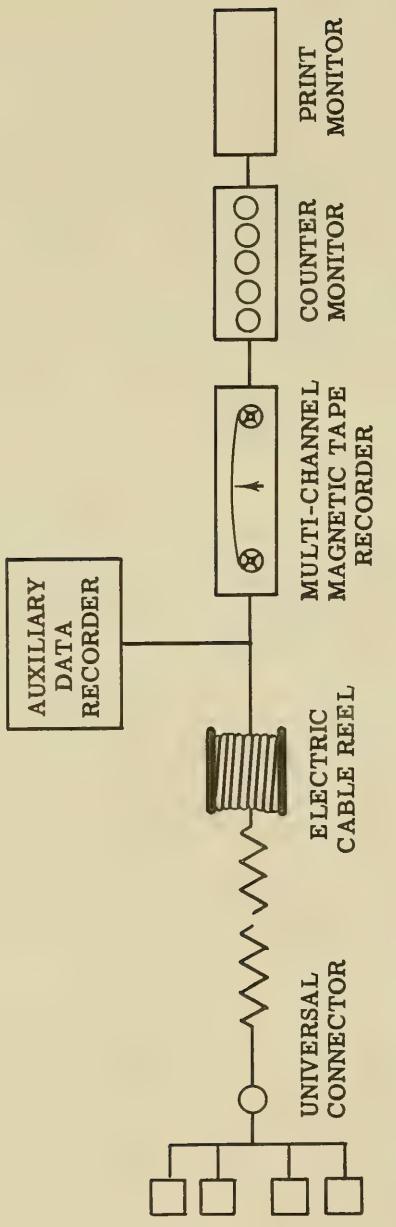
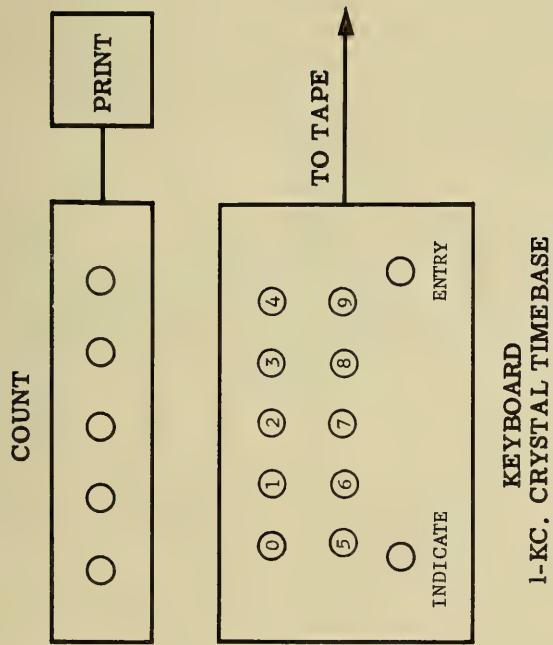


Figure II-1. Shipboard Geophysical Recording System



SAMPLE INFO: 152158   216432   3101058   4432117950   51621   612560   712   81232							
FIRST DIGIT KEY							
1	CRUISE	3	DATE	5	TIME	7	TYPE MEASUREMENT
2	SEQUENCE	4	POSITION	6	DEPTH	8	CALIBRATION NO.

Figure II-2. Auxiliary Data Recorder

Figure II-2 shows the general design of the marker discussed above. The push-button keyboard controls the time of the gate which in turn controls the number of cycles allowed to enter the magnetic tape. Stability of this system is excellent if, for example, 100 cycle increments are used for the digits 0 through 9. Then by detecting the hundreds place, stable digits can be read which are proportional to the annotation information.

### 3. Record Playback

In order to record and playback both the data and the auxilliary information, a two-channel magnetic tape recorder would be employed. The data channel and auxilliary channel would be designed so that encoding of auxilliary information would automatically interrupt the data channel. When the tape is read, the auxilliary information and the data would be read sequentially as a single channel recording. Figure II-3 illustrates the record and playback technique.

### 4. Reading and Printout

The number of cycles proportional to the digital representation of auxilliary information would be read by an ungated electronic counter triggered and reset by the time interval between digits. The data channel would be read by a gated electronic counter. Both readings then could be printed out on a compatible printer, punched on a card, or converted to EDP equipment tape.

### 5. Calibration

Each transducer would have a calibration certificate which would accompany the instrument. In addition, a punch card file of calibrations for all transducers would be maintained at the Hydrographic Office. This information would be used to convert the frequency to the desired units of measurement. Methods for checking field calibrations would be established and required at specified intervals.

## C. CONCLUSION

The requirements mentioned in the introduction to this report are believed to be met by the system described. An important criterion for successful data recording and processing with this system is that a standard format for the auxilliary information be established. This system will provide a nearly continuous record of any geophysical variable that can be converted to a variable audio frequency. The readout in the form of punch cards provides for economical and

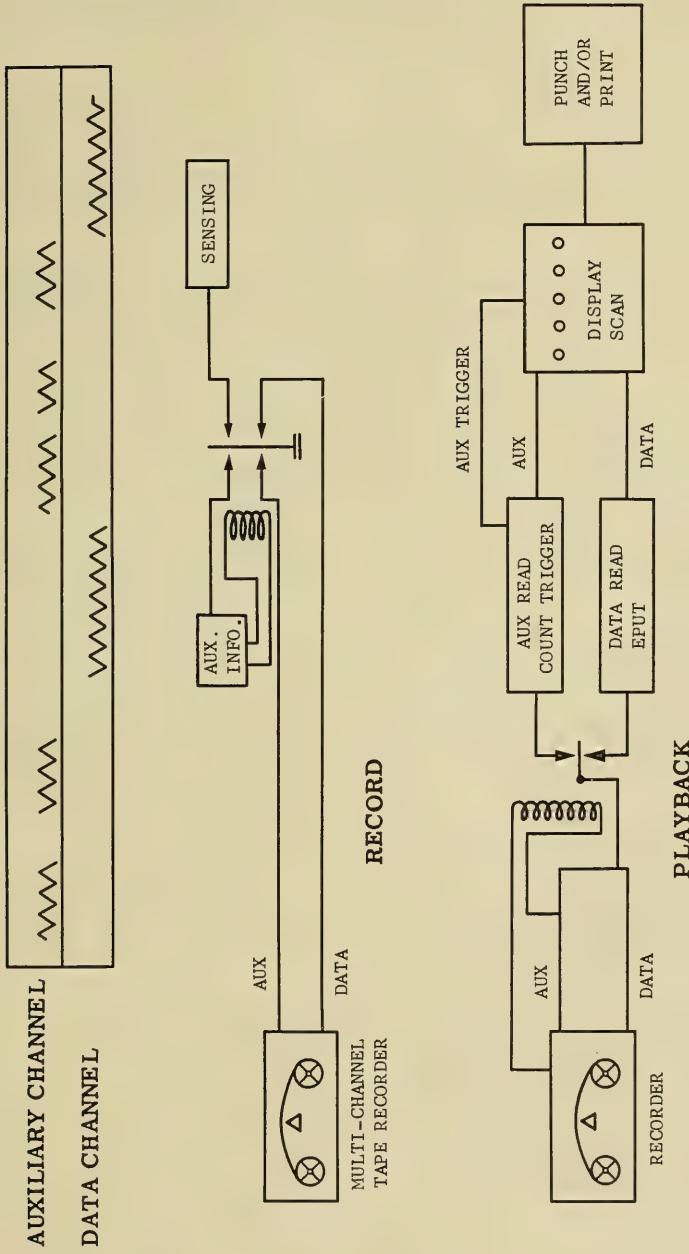


Figure II-3. Record and Playback Circuits

easy sorting and analysis, but the system is flexible enough to work into any type of EDP equipment once the conversion to audio frequency is made.

#### D. RECOMMENDATION

It is recognized that one system of data taking will not satisfy all requirements. However, it is important to establish one good basic method by which the majority of the field measurements can be recorded and processed.

It is the recommendation of this Committee that the prototype system already begun continue to be tested and evaluated by the Instrumentation Division.

### III. SEA WATER TEMPERATURE MEASUREMENTS

Murray H. Schefer

#### A. INTRODUCTION

The measurement of sea water temperature must be regarded as the most fundamental in oceanography. It is also the ocean variable about which the most data have been collected. However, it reasonably can be assumed that temperature measurements will continue to be collected and will be studied intensively in an attempt to solve many oceanographic problems.

Although temperature measurements date back to the early days of science, and the techniques and instruments for making these measurements have reached a high degree of accuracy, sensitivity, and reliability, special problems associated with the measurement of sea water temperatures leave much to be desired, and there exists considerable room for improvement. The measurement of sea water temperatures has been complicated by several factors. The most important of these are:

1. No standard data requirement can be stated. The specifications for temperature measurements depend upon the use to which the data will be applied or upon the specific problem under study.
2. The sea must be considered as consisting of several layers in each of which the thermal structure is generally different and the thermal processes actually differ. Further, the time scale for these processes varies considerably in the different layers, and the magnitudes of the changes are of different orders.
3. The concealment afforded by the oceans, which may be an advantage in military operations, works against the scientist or surveyor attempting to measure physical variables. Communication between the sensing element and the observer, or a recorder, becomes complicated. Also the effects of water under great pressure create many problems of design.
4. Equipment designed for use at sea must be rugged and reliable. Ruggedness often is obtained at a cost of sensitivity. Reliability is particularly important because too often the proper maintenance facilities and personnel are not available aboard the survey ship.

These, then, are the major problems associated with the measurement of sea water temperatures. Other minor problems also exist that

must be solved. Another problem, not specifically associated with the oceans, but one which must be resolved before design can proceed, is whether point or continuous observations are desired. Finally depth measurement is a problem which must be regarded as an integral part of not only temperature measurement but also of any other variable being measured below the ocean surface. All of these variables must be positioned with regard to time, latitude, longitude, and depth.

Temperature is used, directly and indirectly, to describe a wide variety of phenomena and processes taking place in the oceans. At the Hydrographic Office, temperature values are used in the following applications.

#### 1. Description of the environment

Sea water temperature can affect the performance of equipment and personnel.

#### 2. Sound velocity computations

Of the three variables, temperature, salinity, and pressure, that affect sound velocity, temperature has the greatest effect.

#### 3. Calculation of density

Density is a factor in buoyancy problems.

#### 4. Electrical conductivity of sea water

Temperature and salinity are the variables that affect electrical conductivity.

#### 5. Current studies

Where current measurements are lacking, much information can be deduced from a study of the spatial and temporal distribution of temperature.

#### 6. Temperature prediction

Underwater sound transmission is closely dependent upon the thermal structure of the ocean. The development of sonar prediction techniques and RAFOS systems requires a thorough understanding of the thermal structure and the changes occurring therein.

## 7. Calculation of ice potential

A technique currently utilized as a part of the sea ice prediction program requires accurate thermal structure data.

## 8. Calculation of currents from dynamic topography

Very accurate temperature values are necessary to develop the density structure from which general circulation can be determined.

## 9. Temperature-salinity verification

To check the validity of deep oceanographic data, use is made of the temperature-salinity, or T-S, identification.

## B. ACCURACY AND SENSITIVITY

For most of the uses of temperature data, a temperature accuracy of  $\pm 0.1^{\circ}\text{C}$  is sufficient. However, for buoyancy problems, temperatures to an accuracy of  $\pm 0.05^{\circ}\text{C}$  are desired. For calculations of dynamic topography temperature values to  $\pm 0.02^{\circ}\text{C}$  are necessary.

Accuracy, however, is not the only requirement. The measuring device should be sufficiently sensitive to describe the horizontal and vertical variations in the temperature distribution and the changes in distribution that are constantly occurring. This latter requirement in some problems is at least equal to, if not more important than, that of accuracy. The criteria for determining the desired sensitivity are both the time factor of naturally occurring temperature variations and the speed desired for lowering and raising the instruments. A response time of 0.2 second for attaining 90 percent of a change of  $5.0^{\circ}\text{C}$  is desired.

## C. PRESENT TEMPERATURE MEASURING EQUIPMENT

The greatest portion of the sea temperature observations on file at the Hydrographic Office has been collected with four types of equipment: bucket thermometer, intake thermometer, bathythermograph (BT), and reversing thermometer.

### 1. Bucket thermometer

A large percentage of surface water temperatures has been obtained by measuring the temperature of a water sample scooped up

in some container or bucket. No attempt ever has been made to standardize the thermometer, bucket, or techniques. Therefore, although many observations are of high quality, many are poor. The observation is a point type that is recorded by hand. Bucket thermometers generally are graduated in 1°F divisions. Improved bucket thermometers have an elongated scale which permits easier reading to  $\pm 0.1^{\circ}\text{F}$ . If properly taken, bucket temperatures can be obtained to this accuracy.

## 2. Intake thermometer

Another large percentage of surface water temperatures is obtained from the intake thermometers on ships. Very often these temperatures may be slightly higher than the *in situ* temperature. This temperature difference is caused by the location of the thermometer inboard of the intake opening and the heating effect of the ship itself. On some ships, temperatures are automatically recorded, but on many they must be read and recorded by hand. Surface temperatures with more accuracy and in greater quantity can be obtained with a properly designed, properly located instrument.

## 3. Bathythermograph (BT)

The existing continuous subsurface temperature measurements for the upper 900 feet of the oceans have been obtained with the bathythermograph (BT). This instrument obtains a continuous trace of temperature versus depth. Three models exist for use to depths of 180, 450, and 900 feet, respectively. Accuracies of  $\pm 0.2^{\circ}\text{F}$  and  $\pm 1$  percent of full scale can be obtained from a BT that is carefully calibrated and expertly handled. However, study of the BT data received in the Hydrographic Office indicates that this accuracy rarely is achieved. The main reasons for inaccuracy are mishandling and abuse of the instrument and the long intervals between calibrations, which must be made at shore stations because of the rather elaborate equipment needed to produce the pressures associated with depth. A BT in use is checked by comparing its surface temperature indication against that of a bucket thermometer. However, differences between the two values may not necessarily mean that the BT is at fault.

The BT record also does not lend itself readily to mass data handling methods. The present method of recording BT temperature values on punch cards from discrete points on the trace negates to a large extent the advantage of the continuous trace. The fact that as many as three punch cards are required to record the desired data from a single BT trace gives an idea of the magnitude of the problem.

#### 4. Reversing thermometer

Nearly all observations of sea water temperatures below 900 feet have been made with reversing thermometers. First introduced in 1874, the reversing thermometer remains today the most reliable and accurate means of measuring sea temperatures, particularly deep ocean temperatures. Also, the differences between the corrected temperature values from paired protected and unprotected reversing thermometers will indicate the depths of the observations. Good reversing thermometers can give temperature to  $\pm 0.02^{\circ}\text{C}$  and depth to  $\pm 0.5$  percent of the actual value. (A Japanese scientist has built a reversing thermometer accurate to  $\pm 0.005^{\circ}\text{C}$ .)

However, reversing thermometers give temperature information from discrete depths or points instead of the more desirable continuous record; interpolation often is necessary for comparison of temperatures at standard depths. Nor can reversing thermometers provide an instantaneous record; when the thermometers are back on deck they are read, and the readings are recorded and corrected to obtain the in situ temperature. Reversing thermometers must be calibrated periodically or whenever there is reason to suspect their accuracy. The calibration equipment is also rather elaborate if the pressure factor is to be taken into account.

#### 5. Other devices

Oceanographic institutions and laboratories all have at some time or other designed and built one or more different types of electric or electronic temperature-depth measuring devices. However, no single device has withstood the test of time to the extent that it has been generally adopted and used by others. In fact, most of these devices have been discarded by the laboratories of their origin. Two systems recently have shown promise and are discussed in greater detail below.

Greater success has been achieved in the continuous measurement and recording of sea surface temperatures than in measurement of temperatures at depth because the absence of the pressure factor has made the solution much easier. Surface "thermitows" have been devised that consist essentially of a sensitive resistance thermometer coupled to an automatic recorder. The main difficulty of this system at present is the processing of literally miles of sea surface temperature records that are obtained with this equipment.

#### D. PRESENT DEVELOPMENT OF TEMPERATURE-DEPTH INSTRUMENTS

The most promising developments in instrumentation to measure temperature at depth are the Snodgrass-type BT and the Richardson chain. Basically the Snodgrass instrument senses temperature with a thermistor and depth with a vibrating wire transducer. A Wein bridge converts temperature electronically from a resistance change to a varying frequency, and the transducer is basically a frequency-sensitive device. The frequencies for temperature and depth are transmitted to the ship by a single conductor cable with a sea water return. These frequencies are then fed to a magnetic tape recorder and/or filtered on deck, digitized and converted to temperatures, or they may be converted to voltages and fed to an x-y recorder. The Snodgrass-type BT can give a continuous picture of the temperature structure with depth.

The Richardson chain is essentially a series of thermistors at fixed intervals on a cable which is suspended from a ship to make continuous observations of temperature with time at several fixed depths. The resistances of the sensing elements are detected sequentially and either recorded on a potentiometer strip chart recorder or digitized with a shaft position encoder and recorded on punch cards.

The techniques represented by these two instruments are at the present time the most promising for measuring ocean temperature at varying depths and at fixed depths with time.

#### E. CONCLUSIONS AND RECOMMENDATIONS

Requirements exist for a number of temperature measuring instruments. These instruments fall into two categories: either routine or survey. The fundamental differences between these two categories are that routine instruments must be simple and rugged for use by nonscientific observers in routine observations, whereas survey instruments must provide a high order of data accuracy for use by scientific observers in special observations. Instruments in the routine category are the standard bathythermograph, a hull-mounted temperature probe, an air droppable telemetering BT, and an electronic helicopter BT. Instruments in the survey category include an electronic bathythermograph (single sensor, temperature continuous with depth), a thermocline recorder (multiple sensors, temperature continuous with time), and an airborne radiation thermometer.

## 1. Routine instruments

### a. Standard bathythermograph

For synoptic description of the thermal structure, large volumes of data taken by nonscientific personnel are required. For this purpose the standard BT is considered to be the most valuable instrument that will be available for many years. Mechanically, the standard BT is an excellent instrument. It is rugged, simple to operate, and relatively inexpensive. Its potential accuracy is believed to be limited only by the ability to read the trace against the grid (about  $\pm 0.2^{\circ}\text{F}$  and  $\pm 1$  percent of the full depth scale). This potential accuracy usually is not reached because existing observational and calibration procedures are not adequate.

Studies of mechanical and procedural inaccuracies are being made and are expected to result in a modified standard operating procedure that will include a simple technique for a partial field calibration. Required improvements for future BT instrumentation include built-in calibration devices, increased depth range to 3,000 feet and a winch to handle the additional wire involved, increased resolutinal capability of the slide, and a design for rectilinear grid coordinates to allow automatic and semi-automatic processing and analog-to-digital conversion of the temperature trace.

It is recommended that the Hydrographic Office support further development of the present bathythermograph with a view toward achieving the improvements listed above. The requirement for a built-in calibration device should be given first priority. The Hydrographic Office should continue investigation and evaluation of the problem.

### b. Hull-mounted temperature probe

A great need exists for a bow-mounted surface temperature probe on all ships reporting marine weather and especially ships participating in the oceanographic surveillance net. The resulting data would replace the injection temperatures which are nearly always erroneous. The instrument should record remotely on the bridge where time and position data may be annotated on the record in the same way as they are on depth records. These temperature records should be filed with the Hydrographic Office for possible subsequent analysis, but most important, reliable radio reports of these sea surface temperatures would contribute immensely to a better understanding of transient horizontal temperature distributions in the

oceans. The accuracy required for such a probe is  $\pm 0.1^{\circ}\text{C}$ , and the probe should record a temperature range of  $-2^{\circ}$  to  $32^{\circ}\text{C}$ .

It is recommended that the Hydrographic Office develop the performance characteristics of a hull-mounted temperature probe and that action be initiated to have such a system installed as soon as possible on the USS SAN PABLO and USS REHOBOTH for test and evaluation.

c. Airborne telemetering BT and electronic helicopter BT

An airborne, expendable BT, now in the prototype stage of development is expected partially to satisfy the requirement for such an instrument when its development is complete. The accuracy which reasonably might be expected in the near future is  $\pm 0.5^{\circ}\text{C}$  for a temperature range of  $-2^{\circ}$  to  $32^{\circ}\text{C}$ . The expected depth accuracy is  $\pm 10$  feet with a depth range to 500 feet.

An electronic helicopter BT, also in the prototype stage, is expected to satisfy the requirement for such an instrument in its final production form. Accuracy requirements are  $\pm 0.1^{\circ}\text{C}$  for a temperature range of  $-2^{\circ}$  to  $32^{\circ}\text{C}$  and less than two percent depth error over a depth range to 500 feet.

It is recommended that the Hydrographic Office closely follow the development of airborne telemetering BT and the electronic helicopter BT and make every effort to obtain early production models of these instruments for test and evaluation.

2. Survey Instruments

a. Electronic BT (single sensor, temperature continuous with depth)

The need for this instrument is urgent, since the many relationships that remain to be discovered in order to forecast thermal structure reliably depend upon the ability to measure the thermal structure with a high degree of accuracy not possible with present techniques. Such an instrument should have a consistent, reliable accuracy of at least  $\pm 0.01^{\circ}\text{C}$  over a temperature range of  $-2^{\circ}$  to  $32^{\circ}\text{C}$ . The depth error should be less than  $\pm 6$  feet over a depth range to 1,500 feet. The response of the temperature sensor should allow a descent and ascent rate of 200 feet per minute with a minimum of a 90 percent temperature response within a 10-foot interval. Data should be displayed on a rectilinear x-y recorder. Sampling rates as

fast as ten minutes per down-up cycle should be possible without overloading any components.

Work at the Hydrographic Office indicates that electronic bathy-thermographs which employ a single thermistor and contain the electronic circuitry which is required to convert the output to a frequency signal in the "fish" have a tendency to drift. This drift is caused by changes in the ambient temperature which in turn affects the characteristics of the circuit.

As a result, much work has been put into an instrument called the Hydro Linear BT. In this device only the sensors are in the "fish". The temperature element consists of two thermistors in a series/parallel circuit, one of the thermistors being in series with a precision wire-wound resistor. The purpose of this arrangement is to overcome the nonlinearity of the thermistors. Also in the "fish" is a pressure transducer of a helical tube-type. The ranges of the instrument are 0° to 30°C and 0 to 1,500 feet. Initial tests indicate that an accuracy of  $\pm 0.01^\circ\text{C}$  can be achieved. The data are plotted on an x-y recorder. Full scale ranges of 0° to 1°, 0° to 5°, 0° to 10°, 0° to 20°, and 0° to 30°C can be selected. Similarly, depth scales of 0 to 150, 0 to 350, 0 to 750, and 0 to 1,500 feet can be selected. A depth accuracy of  $\pm 7.5$  feet for the 1,500-foot range is claimed. At present, the device cannot be used from a ship that is underway.

The use of thermistors is proving to be a problem. The facts that they are nonlinear, require aging to give repeatable results, and are difficult to match raise many problems in their use in temperature probes.

Other problems also have become apparent. If the electronics are taken out of the "fish", then a multiconductor cable is necessary. The increased cable diameter requires larger winches and makes it difficult to get the "fish" to depth if an underway device is being sought.

b. Thermocline recorder (multiple sensors, temperature continuous with time)

Thermistor arrays such as the Richardson chain are increasing the understanding of temperature distributions in the ocean. A requirement exists for one or more instruments of this type. The Hubbard isotherm plotter, which is used at present with the chain, is not considered to be very well suited for the subsequent processing

of large volumes of data. Some other type of read-out, such as punched cards or punched tape, would be preferable. The temperature error should not exceed  $\pm 0.1^{\circ}\text{C}$  for the temperature range of  $-2^{\circ}$  to  $32^{\circ}\text{C}$ . The depth error should be less than two percent not including the error resulting from linear interpolations between thermistors. The optimum spacing of thermistors is not known but is believed to be about 25 feet.

The major expense and difficulty of handling of the Richardson chain lie in the winch and mechanical chain linkage. This expense largely would be eliminated if the instrument were not designed for underway use. Although a requirement exists for such an instrument to be used underway, a greater requirement exists for an instrument which need not be engineered for underway use. Time-series studies of internal waves from an anchored ship and Texas Tower applications are two uses of such an instrument.

A contract for a shipboard thermocline recorder has been let. If evaluation of this equipment is favorable, it is recommended that contracts be let for other types of these recorders.

#### c. Airborne radiation thermometer

This important survey tool has wide application in ice prediction as well as in temperature prediction. Although much experimentation still is required to realize the full potentialities of an airborne radiation thermometer, it already has proven its value as the most practical way of obtaining nearly synoptic, gross, sea surface temperature data. The mean error of this instrument as tested by the Hydrographic Office is approximately  $\pm 0.2^{\circ}\text{C}$ , depending upon the competence of the operator. Since this inherent error is primarily the result of atmospheric transmission and in some cases sun glitter, the relative accuracy is not much better than the absolute accuracy. Better accuracy is believed possible with the use of associated instruments for sampling the atmospheric gradients between the sensor and the sea.

It is recommended that refinement of the airborne radiation thermometer be continued.

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#### IV. SALINITY AND DENSITY MEASUREMENTS

Murray H. Schefer

##### A. INTRODUCTION

The salinity of sea water is defined as the total amount of dissolved material in grams, excluding organic matter, contained in one kilogram of sea water. The term density, generally used in oceanography, is really specific gravity which is the ratio of the mass per unit volume of a sea water sample to the mass of an equal volume of distilled water at 4°C and standard atmospheric pressure. In the c.g.s. system the density of distilled water at 4°C and atmospheric pressure is equal to unity, and therefore specific gravity is numerically identical with density.

Salinity concentration is expressed in parts per thousand, or per mille, for which the symbol ‰ is used. It has been found that regardless of the absolute concentration, the relative proportions of the different major constituents are virtually constant, except in regions of high dilution (low salinity) where minor deviations may occur. Density is expressed as a pure number.

In oceanography, salinity is of importance because it is one of the three variables which affect the density of sea water. The other two variables are temperature and pressure. The density of sea water, and especially changes in density, affect a number of oceanographic factors. Some are: propagation of underwater sound, propagation of light under water, buoyancy of submarines, vertical mixing, generation of ocean currents, and stratification.

Owing to the nearly constant composition of the dissolved solids, the determination of a single element present in relatively large quantity can be used as a measure of the total salinity. Chloride ions make up approximately 55 percent of the dissolved solids and can be determined with reliability and accuracy. The empirical relationship between salinity and chlorinity is: Salinity = 0.03 + 1.805 x Chlorinity. Thus, the traditional method of determining total salinity has been to raise uncontaminated sea water samples to the surface and to determine quantitatively the concentration of chloride ions and apply the formula given above. The concentration of chloride ions is determined by titrating a sample of sea water with a known solution of silver nitrate. This technique as practiced today is known as the Knudsen Method. The end point of the titration is determined by the use of an indicator that changes color. Titrations can be performed so that

results of  $\pm 0.02\%$  salinity are obtained. This method, however, has several disadvantages. These are:

1. Best results are obtained in a laboratory ashore. Water samples, therefore, must be preserved carefully and stored to prevent changes in concentration.
2. The titration is tedious and time-consuming.
3. Exact determination of the end-point is subject to operator error.

A recent modification of the Wenner-Smith-Soule conductivity bridge has proven extremely successful, and use of the bridge undoubtedly will take the place of volumetric titrations in those laboratories which can obtain the equipment.

## B. FIELD INSTRUMENTS

Oceanographers have recognized for a long time that it would be highly desirable to measure salinity *in situ*. The problems of sample stowage, tedious and time consuming titrations, and personal error thus would be eliminated.

In industrial and laboratory chemistry, instruments have been devised which can be referred to as analysis and/or concentration instruments. These instruments depend upon either the chemical or physical properties of the unknown.

*In situ*, instruments for oceanography make use of the physical properties of salt water and have been designed or proposed around the measurement of: electrical conductivity, specific gravity, and refractivity. Of the physical properties of sea water used to determine salinity, electrical conductivity has received the most attention and has been used for this purpose by a number of investigators. Conductivity varies nonlinearly with both temperature and salinity, increasing with increased salinity, and increasing with increased temperature. Therefore, both conductivity and temperature must be measured simultaneously to obtain an accurate salinity. The two main difficulties in using conductivity are polarization of the electrodes and the large variation of conductivity with temperature.

Polarization is an electrode surface effect and can be considered as an additional resistance and capacitance in series with the cell. The additional polarization resistance depends upon many factors,

including the cleanliness of the electrode surfaces, and can be expected to change with time. Unless the polarization resistance is small in comparison with the total cell resistance, the results obtained will not be reliable. The ratio of polarization resistance to cell resistance depends upon cell geometry, electrode material, frequency, temperature, and conductivity. For laboratory studies of electrolytic conductivity, the classical method of reducing the effect of polarization has been to use "platinized" platinum electrodes (electrodes coated with a layer of finely divided platinum deposited electrolytically) and to use a frequency of atleast 1,000 c.p.s. When the greatest accuracy is required, the platinized electrodes must be treated very carefully: they must be kept wet at all times, must not be touched, and must be kept free from oil and grease and from organic contamination. These requirements have made use of such electrodes in field instruments difficult. However, some of these difficulties can be overcome by providing interchangeable electrodes, by replatinizing the electrodes at regular intervals, and by checking frequently against standards.

Laboratory measurements of the electrical conductivity of a solution usually are made with a two-electrode cell. When this type of cell is immersed in a solution the measured conductance includes the conductances of the paths both within and external to the cell. Since the cross-sectional area of the external shunt path may be very large for a cell submerged in the sea, the external conductance will be large compared to the conductance within the cell. A cell with an electrode at each end may be effectively short-circuited when used in this way.

To avoid this difficulty a cylindrical cell with three coaxial electrodes has been designed. One electrode is at the center of the cell and one at each end. The two outer electrodes are connected together, and the potential is applied between them and the center electrode. The lead to the center electrode is insulated, and approximately half of the current in this lead flows through the sea water to each end electrode. Inasmuch as the two paths from the center electrode are in parallel, the measured conductance is the sum of the conductances of these paths. Since the two other electrodes are short-circuited together, they are at the same potential, and no current will flow between them through any external shunt path. Thus, the measurements are independent of external shunt conductances, and the cell constant may be determined without the need for duplicating the actual conditions of use.

Derivation of salinity or chlorinity directly from measurements of conductivity requires use of either a servo system to compute chlorinity from measured values of temperature and conductivity or compensation for the effects of temperature. Such a computing servo system

is difficult to design and adjust and is a problem for use in field equipment where size and weight should be kept to a minimum. Compensation for temperature is easier and is obtained by placing a temperature sensitive resistor close to the conductivity cell and connecting it to the arm of the bridge on which the resistance of the cell is measured.

The literature contains many references to in situ conductivity instruments, but the four described below have received the most attention and mention in the literature. Also, several models of each have been produced and used in the field.

### 1. Salinity-temperature-depth recorder (STD)

The salinity-temperature-depth recorder (STD), developed at the Woods Hole Oceanographic Institution and first described in 1948, provides a continuous trace of the three variables on a three-channel strip chart recorder. An underwater unit, composed of a conductivity cell, a nickel resistance thermometer, and a pressure-operated depth element, is connected by a multi-conductor cable to the deckside unit which contains the amplifiers, salinity computing circuit, and recorder. The recorder provides traces of salinity in two overlapping ranges of 20‰ to 32‰ and 28‰ to 40‰, temperature in the range 28° to 90°F, and depth in two ranges to 1,200 feet. The lower limit of 20‰ in the salinity range restricts the usefulness of the instrument in nearshore operations, and an accuracy of  $\pm 0.3\%$  limits its utility in open ocean studies. Nevertheless, this instrument has been used extensively by WHOI personnel.

### 2. Conductivity-temperature indicator (CTI)

This instrument was designed and constructed by the Chesapeake Bay Institute primarily for estuarine studies. Thus, it has a conductivity range for salinities from 0‰ to 35‰ and a temperature range of -2° to 32°C; it contains no depth measuring element. The underwater element consists of a two-electrode, H-type conductivity cell and a nickel resistance thermometer. Temperature in degrees centigrade and conductivity in millimhos are indicated on a pair of four-digit counters mounted on the housing for the amplifier and servomechanism.

A comparison was made at the Chesapeake Bay Institute between readings from the CTI conductivity scale and conductivities computed by using CTI temperature values and the titrated chlorinity values of simultaneously collected water samples. This comparison indicated

an accuracy of approximately  $\pm 0.5\%$  of chlorinity ( $\pm 0.93\%$  of salinity). It also has been concluded by CBI from 679 simultaneous measurements by two such instruments that the standard deviation of measurement errors for the CTI is not greater than 0.05% of chlorinity (0.09% of salinity).

### 3. Temperature-chlorinity-depth recorder

Messrs. B. V. Hamon and N. L. Brown have described a temperature-chlorinity-depth recorder for use in the upper 1,000 meters of the sea. This instrument measures temperatures from 0° to 30°C with an accuracy of  $\pm 0.15^\circ\text{C}$ . The chlorinity range spans about 7% of chlorinity (28.9% to 41.6% of salinity), and the stated accuracy is  $\pm 0.05\%$  of salinity if a surface water sample is taken at each station as a check for cell drift. The accuracy in depth is  $\pm 10$  meters.

The three quantities are recorded sequentially by a single-pen strip chart recorder, each quantity being recorded for five seconds at a time. The underwater unit is suspended by means of an armored steel cable which has a single electrically insulated core. This core carries power down to the underwater unit and brings up the signals from the measuring elements. A simple frequency modulation method of telemetering is used.

Chlorinity is measured by means of a conductivity cell with platinized electrodes. The effect of temperature on conductivity is compensated by using a thermistor. Over the temperature range 5° to 25°C, compensation to within  $\pm 0.02\%$  of salinity can be attained. At 0°C and 30°C, however, the correction is about plus 0.2% and minus 0.2% of salinity, respectively.

It was found necessary to avoid direct electrical connection between the conductivity cell lead and the pressure vessel, as such a connection allowed the flow of electrolytic currents that caused rapid polarization of the electrodes. The oscillator circuit and its power supply are, therefore, insulated from the pressure vessel for direct current, but effectively grounded for alternating current by a capacitor.

The equipment was used at sea about 60 times between April 1955 and November 1957. Nansen bottles and reversing thermometers were used as checks. The difficulty in comparing results was caused mainly by errors in depth. Correction for the effect of pressure on conductivity must be applied and a further correction for temperature.

#### 4. Induction-conductivity-temperature indicator

A development which seeks to avoid the complications of electrodes is the induction-conductivity-temperature indicator developed at the Chesapeake Bay Institute. This device operates through the inductive measurement of an electric current which has been induced in a sea water path. The sensing head consists of two iron-core toroidal windings potted in an insulating resin. One winding is excited by a 115-volt, 60-c.p.s. electrical signal; the seawater path through the hole in the center of this toroid acts as a one-turn secondary of a transformer and, consequently, has about 0.2 volt induced in it. The amount of current flowing depends primarily upon the length and diameter of the hole and upon the conductivity of the water in the hole. The current flowing in the sea water is measured by means of the second toroid which is mounted adjacent to and coaxially with the existing toroid.

No sea-water-to-metal contact exists in this system, so the problems inherent to electrodes are eliminated. The system is essentially independent of line frequency variations over a moderate range of several cycles per second. Stability of the instrument depends wholly upon the dimensional stability of the resin "doughnut" and the stability of the electrical components.

Laboratory tests have shown this device to be capable of measuring conductivity to  $\pm 0.02$  millimho ( $\pm 0.02\%$  of salinity) over the entire ranges of temperature and salinity encountered in estuarine and marine environments.

#### 5. Sound velocity meter for in situ salinities

The Hydrographic Office has several models of the sound velocity meter developed at the National Bureau of Standards. This meter has an inherent accuracy of  $\pm 0.1$  foot per second, but the present read-out system allows an accuracy of only  $\pm 1.0$  foot per second. A read-out accuracy of  $\pm 0.2$  foot per second coupled with the simultaneous measurement of temperature to  $\pm 0.02^{\circ}\text{C}$  would provide in situ salinity of  $\pm 0.05\%$ .

#### 6. Vibrating rod densitometer

William S. Richardson of the Woods Hole Oceanographic Institution has described a vibrating rod densitometer for measuring density in situ. If such a device were developed, it is conceivable that it

could be coupled with a temperature sensor to give values of density and temperature from which salinity could be derived.

A simple form of the densitometer would consist of a tube rigidly clamped in a heavy base and made to vibrate at its resonant frequency by feeding the output of a pickup coil into an amplifier which then excites a driving coil. If the tube is made of a nonmagnetic material, a short sleeve of iron or steel is firmly attached to the free, vibrating end. This is in essence an electrically driven tuning fork. Such devices have a very sharp resonance peak and are, therefore, inherently very stable in frequency. The frequency at which the rod vibrates is determined by its length, its mass per unit length, and the strength of the material from which it is constructed. The stability with changes of temperature is determined by the variation of the above quantities with temperature. For the liquid-filled tube the mass per unit length and, therefore, the resonant frequency will vary with the liquid density. Numerous problems would have to be resolved before such a concept can be developed into a working instrument. Richardson states that such an instrument probably would not be applicable to the direct measurement of the absolute density but that it should be adaptable to measuring changes in density.

### C. LABORATORY INSTRUMENTS

Conductivity instruments also have been developed for the analysis of water samples in the laboratory, either aboard ship or ashore. A number of such instruments are discussed below.

#### 1. Wenner-Smith-Soule conductivity bridge (modified)

The most noteworthy of the conductivity instruments is the modernization of the Wenner-Smith-Soule conductivity bridge which had been used successfully aboard ship by Coast Guard oceanographers since the early 1920's. Improvement of this bridge was initiated by Schleicher and Bradshaw at the Woods Hole Oceanographic Institution in the early 1950's. Paquette at the University of Washington made additional improvements.

Several features make the new instruments quite different from the original Coast Guard model. One of the main differences is the use of the servomechanism to complete the balance of the conductivity bridge automatically. Although it makes the design electronically more complicated, this feature reduces the strain on the operator that is encountered in the manual, audible method of balancing and lessens possibilities of human error. Also, the improved bridges avoid the

necessity of precise temperature control at a specific value and, instead, depend upon maintaining the identical temperature for the reference cell and the sample being analyzed. Sufficient data are at hand to indicate that these instruments attain an accuracy of  $\pm 0.005\%$  of salinity and a repeatability of  $\pm 0.001\%$  of salinity.

An Australian device of recent design was demonstrated at Woods Hole Oceanographic Institution during the summer of 1960 by Mr. N. L. Brown. Accuracy and repeatability seem to be as good as, or better than, the modified Wenner-Smith-Soule conductivity bridge. It has the additional important advantages that it is much smaller and far less expensive to build. A conductivity bridge built in South Africa seems to be as accurate and falls between the two as far as size and cost are concerned.

## 2. Radio frequency salinity measuring instrument

Another recent development is a technique based on the measurement of the absorption of radio frequency energy by the solution undergoing analysis. This method of analysis seeks to avoid the difficulties encountered with usual conductivity methods while retaining the advantages of speed and flexibility. The distinguishing feature of the radio frequency method is that the "electrodes" are on the outside of the vessel containing the water sample, thus eliminating the problem of electrode fouling. In this method it is necessary only to pass the sample through the radio frequency field; no electrodes come in contact with the sample being analyzed. The radio frequency equipment can be used in the laboratory on individual water samples, or at sea on a continuous stream of sea water pumped through it. This latter application is limited by the depth which can be sampled by such techniques.

In radio frequency salinity measuring instruments, the principal technical problem is that of precisely measuring radio frequency voltage and current. The principle employed in this type of instrument consists of passing a high frequency radio current (14 megacycles) through a column of solution, rectifying the radio frequency current, and measuring the amount of direct current which results. The amount of direct current obtained is related to the impedance presented by the column of solution, and the impedance in turn is determined by the salinity of the solution.

At the end of two years (1952-54) of developmental work by the Texas Agricultural and Mechanical College, the results were summarized as follows: "The objective of the research was an instrument

which would make an essentially instantaneous and continuous measurement of salinity accurate to  $\pm 0.01\%$ . Instruments which adequately fulfilled these specifications were produced, but the research was terminated before all of the desired features could be incorporated into a single instrument. Sufficient scientific and engineering data have been obtained from the series of instruments which have been built to permit the design of final or production models.<sup>11</sup>

E. G. Sandels in 1956 described a radio frequency instrument for the measurement of salinity in estuaries. He stated that he had obtained an accuracy of better than  $\pm 0.33\%$  over a salinity range from 0.2 to 50‰.

In September 1958 G. L. Huebner reported that Texas A&M was, in fact, using an improved radio frequency salinity measuring instrument. He stated that accuracies to approximately  $\pm 0.005\%$  of salinity and difference determinations between samples of the order of  $\pm 0.001\%$  had been attained.

### 3. Automatic chlorinity titrator (ACT)

Another laboratory apparatus, developed at the Scripps Institution of Oceanography, is the automatic chlorinity titrator (ACT). The principle of the ACT lies in electrode reactions and the associated electrode potentials. If a piece of silver wire coated with silver chloride is in contact with a solution in which chloride ions are being precipitated as silver chloride, the potential of the electrode, measured against a suitable reference, will be predictable at all stages of titration and will be related to the volume of silver nitrate added. In the ACT this electrode potential drives a titrating mechanism to the end point, and the volume of added silver nitrate is shown on a counter.

Although a standard deviation of  $\pm 0.0075\%$  of salinity was attributed to this instrument, the ACT has never been generally accepted. Only SIO has successfully built and used it. Around 1954 a model of the ACT was received at the Hydrographic Office but never could be put into successful use without an excessive amount of manpower to operate and maintain it.

### 4. Interferometer

Visitors to the VITYAZ during that ship's visits to San Francisco and Honolulu were shown an interferometer with which the Soviets claim they can determine salinity to  $\pm 0.02\%$ . This technique can be used only in the laboratory. However, its complete independence of electronics makes it especially worthwhile. The principle has been

known for a long time, but the Soviets seem to have achieved a degree of success never before attained. Some observers expressed the belief that the Soviet claim is authentic.

### 5. Beta particle absorption instrument

The measurement of density by beta particle absorption has been suggested by Dr. Donald Hood of Texas A&M as a method of obtaining sea water densities.

Accuracies of  $\pm 0.0002$  gram per milliliter may be obtained for binary liquid mixtures. For complex liquid mixtures, such as sea water, the accuracy would depend upon the degree to which the overall composition of sea water varies.

A laboratory instrument is currently available from Hallikainen Instruments of Berkeley, California. The assembly consists of two radioactive sources, two liquid cells, and two ionization chambers mounted in a temperature controlled block. In normal operation one cell is filled with a reference liquid and the other with either a static or flowing sample of the liquid to be analyzed. Beta particles from each source pass into its corresponding cell where some are absorbed. The transmitted particles pass into the ionization chamber and produce ions which result in the flow of an electrical current. The difference between the two ion currents is amplified and recorded and is related to density differences. Strontium 90 is used as a radiation source and, when assembled in the apparatus, produces a radiation level that is about one-half of the currently accepted safe level for 40 hours per week of exposure.

One major problem that is immediately apparent, but as yet unexplained, is the effect that dissolved gases and organic matter will have on the determinations. These substances, which may substantially alter the in situ density value, may have to be driven off or completely oxidized before analysis.

## D. SUMMARY AND CONCLUSIONS

For in situ measurements, the equipment described by Hamon and Brown, with its accuracy of  $\pm 0.05\%$  of salinity, seems to have attained the greatest degree of success of any of the electrode-type conductivity instruments. However, in order to obtain in situ salinity to a desired accuracy of  $\pm 0.02\%$  the instrument employed must be capable of measuring temperature to  $\pm 0.02^{\circ}\text{C}$  and conductivity to  $\pm 0.02$  millimho.

Therefore, parallel development of more accurate temperature measurement and improved circuitry design should be undertaken.

If theory and the results of laboratory tests of the induction-conductivity-temperature indicator are borne out in field operations, the complete abandonment of all electrode-type equipment probably would be justified.

For the laboratory, bridges constructed by the Woods Hole Oceanographic Institution and the University of Washington have proven to be reliable and accurate instruments. Further improvement should be directed toward individual components and reduction in size and weight. The Russian interferometer appears to be a significant achievement, particularly because of its complete freedom from electronic complications.

#### E. RECOMMENDATIONS

It is recommended that the fabrication, calibration, and field testing of the induction-conductivity-temperature indicator now underway by the Hydrographic Office proceed without deferment.

It also is recommended that consideration be given toward making the conductivity bridge (salinometer) a more portable instrument. This might be achieved by miniaturization of portions of the circuitry and by packaging the total equipment into several components which would be individually more portable. This is being investigated as is the Australian equipment which may meet the requirement.

It is recommended further that the Hydrographic Office continue its investigation of the reported accuracy of the Soviet interferometer and the feasibility of acquiring or building such an instrument that would equal the claims made by the Soviets.

Finally, it is recommended that this Office keep abreast of the development of the beta particle absorption technique.

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## V. PRESSURE (DEPTH) MEASUREMENTS

Murray H. Schefer

### A. INTRODUCTION

All oceanographic measurements must be positioned along three coordinates: latitude, longitude, and depth. The latter, the measurement of the distance to equipment located beneath the sea surface, is discussed in this section. Measurement of the total depth of water is discussed in Section XI.

Although depth is a distance measurement, it has been found more feasible to take advantage of the direct relationship between pressure and depth by measuring pressure and converting it to a depth value. The problem, therefore, is fundamentally one of pressure measurement. Sea water pressure varies between 0.44 to 0.46 p.s.i. per foot of depth, or roughly 0.5 p.s.i. per foot of depth. Much oceanographic survey work is conducted in the range of zero to 5,000 p.s.i., or from the surface to a depth of about 10,000 feet, but measurements to the bottoms of the ocean deeps require equipment with a range to 15,000 p.s.i. Depth measuring equipment should have an accuracy of  $\pm 2$  percent.

### B. INSTRUMENTS

The measurement of pressure, like temperature, is one of the most fundamental in science. As a result, many diverse methods have been devised to accomplish it. Pressure measuring instruments can be classified in several ways. One system of classification describes the instruments as either primary or secondary and depends upon the principle employed.

#### 1. Primary pressure instruments

These instruments are manometers and gauges which can be calibrated without reference to another pressure measuring instrument. The mercury barometer and dead weight scale are examples of such primary pressure instruments. However, these types of instruments generally do not lend themselves to incorporation into over-the-side oceanographic equipment.

#### 2. Secondary pressure instruments

All other pressure measuring instruments are included in this

category. These instruments can be calibrated only by comparison with a primary gauge. Some principles employed and which work best for the pressure range of concern in oceanography are: elastic deformation, change in the electrical resistance of conductors and semi-conductors, and variation in the natural frequency of a vibrating wire.

Many other methods are used in science and industry for measuring high pressures. The three just listed have been used with varying degrees of success in oceanographic work and are considered to show the most promise. The existing literature describes the successful use of Bourdon tubes for depths to 2,000 feet, and the vibrating wire for greater depths; however, the vibrating wire also can be used over the entire range of depth.

a. Elastic deformation

(1) Mercury column

The unprotected thermometer is the earliest satisfactory device for measuring depth in the sea. Primitive models of this instrument were used in the Challenger Expedition of the 1870's, and today refined models remain the most accurate and reliable means for measuring depth. This instrument, which is a mercury thermometer, when subjected to pressure gives a fictitious "temperature" reading that is dependent upon the temperature and pressure in situ. Instruments used for this purpose are designed so that the apparent temperature increase due to the hydrostatic pressure is about  $0.01^{\circ}\text{C}$  per meter. An unprotected thermometer is always paired with a protected thermometer, by means of which the temperature in situ,  $T_w$ , is determined. The correction to be added to the temperature of the unprotected thermometer,  $T_u$ , is obtained by applying  $T_w$  in the proper equation. The probable error of depth obtained by an unprotected thermometer is about  $\pm 5$  meters for depths less than 1,000 meters, and at greater depths it amounts to about  $\pm 0.5$  percent.

The only satisfactory depth measuring instrument available at the Hydrographic Office is the unprotected reversing thermometer. However, although this device can measure depth accurately, it has the same disadvantages that the protected reversing thermometer has for measuring temperatures (Section III).

(2) Bellows

The familiar bathythermograph measures and records,

as a continuous trace on a smoked glass slide, sea water temperature versus depth. The depth element of the 180- and 450-foot models consists of a spring-loaded piston enclosed in a flexible envelope made of three brass bellows soldered together; in the 900-foot instrument the spring is outside of the bellows assembly. The slide holder is attached to one end of the bellows. As the instrument is lowered into the sea, increasing water pressure tends to collapse the bellows and compress the spring, thus moving the slide holder. The springs in the three BT models are of such proportions that, with a pressure corresponding to their respective depth ratings, the slide will move 0.7 inch. If the depth limit is exceeded, the bellows and spring become distorted, and the depth calibration of the BT is altered. Within its operating range, the depth sensor of the BT is accurate to about one percent of total depth.

### (3) Hollow spring

The Bourdon tube is a hollow spring. In oceanographic work the Bourdon tube usually is coupled to a variable resistor or to a potentiometer circuit which is used as a transmitter. The North Pacific Fisheries Exploration and Gear Research have developed such a depth telemeter. The sensing element contains a Bourdon tube which actuates a pressure potentiometer. Extensive use at sea in trawling work seems to bear out the reliability and accuracy of this instrument.

Karl Schleicher described a deep electronic bathythermograph in 1953. Pressure is measured by means of a helical Bourdon tube that has a range of zero to 2,700 p.s.i. The Bourdon tube moves the core of a Schaeivitz transformer. The recorder is in the fish. Sensitivity, the smallest reproducible change in the measured variable which will cause a noticeable and measureable deflection of the recording pen on the drum, is five p.s.i. (about ten feet). No data are given on the accuracy of the instrument under field conditions.

Also in 1953, S. J. Knott described a depth meter containing three Bourdon tubes with ranges of 250, 500, and 1,000 feet. Laboratory calibration gave an accuracy of  $\pm 1$  percent or less of full scale.

In 1955, Boden, Kampa, Snodgrass, and Devereaux described a depth telerecording unit which employs a Bourdon tube to actuate a potentiometer. An accuracy to within  $\pm 0.5$  percent of the actual depth in the range of zero to 1,000 meters was stated.

Willard Dow, also in 1955, described an acoustic telemetering depth meter. The submerged device contained a stable heterodyne

oscillator, the frequency of which was varied between 16 and 26 kilocycles by a variable capacitor driven by a Bourdon tube. A hydrophone was towed at the surface 1,000 to 1,500 feet behind a ship, away from noise of the ship. Signals could be heard from a 1,500-foot depth while underway and from a 3,200-foot depth when not underway. Early field trials indicated an accuracy between five to eight percent of the actual depth. This accuracy was improved to about one percent of full scale (1,500 feet).

Bourdon-actuated depth measuring elements purchased by the Hydrographic Office are giving erratic results in the field. Two models were purchased: a 200-foot model, and a 10,000-foot model. The manufacturer states a full-scale accuracy of  $\pm 2$  percent. Calibrations by this Office show that the meters do meet the specification. However, this two percent of full scale may show up, and does, at all depths. Thus, for the 10,000-foot instrument, the reading at a calibration pressure of 200 feet may be 400 feet. The calibration data for measurements from the 10,000-foot instrument indicate that the meters should be subjected to much more detailed examination in the laboratory. The calibrations (and techniques) are too sketchy to permit any definite conclusions concerning the repeatability (or reliability) of the meters, and some of the calibration data indicate a degree of erratic behavior. The calibration data for the 200-foot instruments are more satisfactory, but these data also are insufficient to permit conclusions concerning repeatability. Field tests aboard the USS LITTLEHALES showed good agreement between three 200-foot meters. However, conditions precluded controlled measurements to determine accuracy. Both models have performed erratically in the field. To date insufficient quantitative data exist to help determine the causes of error. The very small scale on the face of the indicator is undoubtedly one source of error: A scale division of one-sixteenth inch equals 100 feet.

b. Electrical resistance change (strain gauge)

Essentially, the element of a strain gauge is an electro-mechanical device which transduces minute changes of displacement to sensible resistance changes proportional to the displacement. The transducer is electrically and mechanically symmetrical. In the center of a stationary frame, an armature is supported rigidly in the plane perpendicular to the longitudinal axis so as to allow free movement along this axis. Connected between rigid pins mounted in the frame and armature are four filaments of strain-sensitive resistance wire which comprise the four elements of a Wheatstone bridge. As the armature

is caused to move longitudinally by an external force, two of the filaments will elongate and the other two will shorten. The resistances of the elongated filaments increase as the resistances of the shortened filaments decrease. The changes in resistances of the filaments will be proportional to their changes in length. The resistance changes of the filaments alter the electrical balance of the bridge to produce an electric signal in the output circuit.

Specifications of a commercial strain gauge are as follows:

(1) Ranges: 0 to 50 to 0 to 1,000 pounds compression. The full-scale displacement is approximately 0.002 inch.

(2) Load limits: two times range in compression

(3) Transduction: resistive, complete balanced bridge

(4) Nominal bridge resistance: 350 ohms

(5) Excitation: 14 volts d.c. or a.c. (rms), including carrier frequencies

(6) Output: 40 millivolts full scale open circuit at 14 volts excitation

(7) Non-linearity and hysteresis: not more than  $\pm 0.5$  percent of full scale

(8) Ambient temperature limits: -100° to 275°F

(9) Thermal coefficient of sensitivity: approximately 0.01 percent per °F from -65° to 250°F. Temperature compensation can be incorporated.

(10) Thermal zero shift: approximately 0.01 percent of full scale per °F from -65° to 250°F.

Strain gauges are used in bottom pressure measuring equipment but, the Hydrographic Office has only one depth gauge which has a strain gauge element. This device has been used to monitor the depth of a towed magnetometer. Prior to its use in the field, the gauge and associated recorder were calibrated on a dead weight scale. However, since depth is not critical in the application, the calibration was superficial.

### c. Frequency variation (vibrating wire)

The vibrating wire transducer is a device that can be used to measure depth and currently is being tested at the Hydrographic Office. The vibrating element is simply a very fine tungsten wire which is stretched in a magnetic field. The wire vibrates at some precise frequency which is determined by the length and tension of the wire. Pressure changes, by varying the tension in the wire, change the vibration frequency of the wire. Snodgrass and Cawley state an accuracy for this device of better than  $\pm 0.25$  percent, as does the manufacturer. A vibrating wire transducer was incorporated into the Hydrographic Office Electronic BT, and this equipment was tested in 1959 in the field. The results were sufficiently successful to warrant the incorporation of this transducer into certain shallow-water field equipment and the further investigation of it for use with deepwater equipment.

### 3. Sonar pinger system

H. E. Edgerton recently (June 1960) described the construction and application of a sonar pinger system for use in determining, with a precision of about one meter, the distance of equipment above the ocean floor. Two types of systems have been used successfully: one for depths to 6,500 feet and the other for depths to 37,500 feet. The system has been particularly successful in positioning underwater cameras at a given distance off the bottom. However, it also can be applied to Nansen bottle casts, bottom coring operations, etc.

A transducer, located with the subsurface equipment, emits short bursts of high frequency energy (12 kilocycles) at one-second intervals. The transmitted pulse travels directly to the surface and also is reflected from the bottom. The converted time difference between the direct signal and the reflected signal gives the distance from the transducer to the bottom. Any sonar receiver or cathode-ray tube display can be used to pick up and display the pulses. An echo sounding recorder is preferred as it gives a graphic picture of the location of the transducer with respect to the bottom and enables maintenance of a constant distance off the bottom.

The conversion of pulse travel time to distance involves the velocity of sound in seawater. Edgerton uses 5,000 feet per second as an approximate value. Use of such a value introduces some error into the use of this device as a depth indicator. Nevertheless, the sonar pinger system seems to show considerable merit for use with oceanographic equipment.

## C. CONCLUSIONS

No satisfactory commercially available oceanographic depth gauge is available today other than the unprotected reversing thermometer.

The problem of developing a telemetering depth gauge that uses commercially available pressure sensors is considered to be within the capability of this Office.

## D. RECOMMENDATIONS

Since September 1959 a vibrating wire depth gauge has been used as part of an oceanographic data collection system installed aboard a submarine and has been evaluated as being reliable and accurate. However, the operational depth of a submarine is fairly limited in terms of deep ocean applications, and it is recommended that this Office continue its development and testing of the vibrating wire depth gauge.

It is also recommended that the Hydrographic Office conduct further calibration tests on the Bourdon gauges to determine their expected accuracies; and if the accuracies are acceptable, this Office then should develop inexpensive Bourdon actuated depth gauges for use to 400, 2,500, and 10,000 feet, respectively. If these tests continue to indicate large errors in these gauges, this Office should endeavor to reconcile these results with results of other users of such gauges.

It is further recommended that the Hydrographic Office investigate the feasibility of employing a strain gauge as the sensor in a depth meter.

Finally, it is recommended that the Hydrographic Office evaluate the sonar pinger system.

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## VI. CURRENT MEASUREMENTS

Quick Carlson

### A. INTRODUCTION\*

An ocean current generally is defined as a horizontal movement of water and may be described at any point in time and place by a vector. This vector comprises speed or "drift" in knots as its magnitude and "set" in degrees clockwise from North as its direction. Currents may be divided for convenience into groups according to their causal factors: (1) Currents related to density distribution, (2) tidal currents, (3) currents caused by wind stress, (4) currents caused by surface waves, and (5) currents caused by river outflow.

Currents may well be the most important dynamic variable in the ocean. Many phenomena are critically controlled by the current behavior. These include:

#### 1. Submarine navigation

Subsurface dead reckoning requires reliable information on deep currents.

#### 2. Sound propagation

Sound transmission is considerably more complicated in areas of turbulence and motion.

#### 3. Thermal structure prediction

Predictions of thermal gradients for sonar operations will be uncertain until the term of advection due to currents can be understood properly and predicted.

#### 4. Dispersal of nuclear wastes

Effluent from atomic shore installations and atomic powered ships and radioactive by-products from nuclear explosions at sea must be distributed by the natural current forces in the ocean. Areas of lethal accumulations must be predicted in advance.

\* Much of the material in this section was extracted from the extremely comprehensive report cited as Reference VI-1 at the end of this Section.

## 5. Transfer of heat over large areas

Climates of great, populated areas such as northern Europe are controlled by the current systems of the oceans.

## 6. Movement of submerged objects

The effects of currents on the movement or burial of submerged objects are only partially understood but are known to be of considerable practical importance.

## 7. Ice movements

Currents, together with winds, are of primary consideration in predicting the movements of ice fields and icebergs.

## 8. Surface navigation

Detailed, prior knowledge of currents in dangerous waterways is essential. Ship routes for decades have been planned to make maximum use of favorable currents.

## 9. Erosion

Bottom erosion and accretion caused by currents require constant hydrographic surveillance of all navigable waterways.

## 10. Biological productivity

The transport of nutrients, oxygen, and waste materials to and away from organisms and the distribution of populations, spores, and eggs are all directly related to currents.

The accuracies in speed and direction required for determining some of the above relationships vary, but in general are about  $\pm 0.1$  knot and  $\pm 10^\circ$  True. Current measuring instruments ideally should have a range of 0.1 to 10.0 knots, but a range of 0.1 to 5.0 knots is considered adequate for 99 percent of the oceans; lower thresholds, however, may be desired for special purposes. These instruments ideally should be unlimited by depth and should allow the measurement of current gradients with depth. Most important of all, instruments should be simple, rugged, and maintenance-free.

## B. METHODS OF CURRENT MEASUREMENTS

Existing methods of current measurements include indirect measurements of density distributions from which currents may be determined, as well as direct measurements of flow. Density distributions in the ocean are related to currents in the same manner that isobaric weather charts are related to winds and do not involve any actual measurements of flow. Density distributions are determined from accurate measurements of temperature, salinity, and depth. These parameters have been discussed in Sections III, IV, and V, respectively, of this report.

Direct measurements of currents may be accomplished by two basic methods: (1) The drift method, the release of freely drifting devices at a given time and place and their subsequent tracking or recovery at some new time and place; and (2) the flow method, the measurement of flow past a point that is fixed geographically.

### 1. Drift methods

Accuracies obtainable by this method are determined by the navigational accuracy with which positions of the drifting device may be fixed, as well as by the ability of the device to be unaffected by influences other than the current under measurement. The primary advantage of this method is that anchoring of the ship is not required.

Drifting devices include woodchips, bottles, cards, confetti, dyes, etc., as well as more sophisticated devices such as drogues, telemetering buoys, and neutral buoyancy floats. Since all of the surface devices are at least partially exposed to the winds and extend to some depth below the water, they may not truly measure surface drift, and data must be viewed with caution. Another technique involving drift is the lowering of current meters from a drifting ship. Frequent, accurate positioning is necessary in this method to correct for the movement of the ship. A difficulty with freely drifting devices is that instantaneous measurements are not possible, and only time-averaged currents may be obtained.

Subsurface currents may be measured by the drift method with drogues suspended at any given depth on a wire between a surface buoy and a weight. The Hydrographic Office has made occasional use of this method to obtain currents as deep as 3,000 feet. The complete device is made at negligible cost from a surplus parachute, piano wire, a weight, and a float. Although the system does not lend itself to automation, certain improvements in buoy design and location techniques

would improve survey efficiency. A high incidence of loss currently is sustained with free-drifting buoys. This loss may be minimized with the use of radio transmitters. Radio locating techniques also will allow a greater number of simultaneous observations.

## 2. Flow methods

The most direct method of measuring currents is to detect their rate of flow past a fixed geographical point. Stationary platforms are required for this measurement, but anchored ships or buoys frequently are used. However, anchored vessels do not completely satisfy the requirement for a stationary platform. Therefore, the minimum accuracy obtainable from an anchored ship or buoy is limited with any flow instrument. The geomagnetic method of determining currents, however, is a notable exception to this statement. Although this method essentially measures the electromotive force induced by sea water flow past a given geographical point, it is possible to sample this force without the movement of the ship influencing the measurement.

Flow may be measured by instruments which operate on various principles. The most popular instruments employ rotating elements or impellers whose speed of rotation is a function of current speed. Other principles include the measurement of dynamic pressure against a pendulum, plate, or pitot tube. Acoustic devices have been used for measuring phase differences between the source and receiver for sound traveling in various directions relative to the current flow. Measurement can be made of the electromotive force generated when an electricity-conducting fluid such as sea water moves through an artificial magnetic field; this force is a function of velocity. Even hot wires or thermistors, whose cooling rate is a function of flow, have been used.

All of these instruments, when used from a moving ship, must depend upon an internal compass to indicate direction.

## C. AVAILABLE CURRENT METERS

Hundreds of current meters have been described in the literature, but only a relative few can be purchased as production items. Some of these are listed in Table VI-1 with approximate prices of the basic sensing units. However, the initial cost of a current meter is a small part of the total cost per observation of current data. Much larger and more pertinent are the costs of operation, maintenance, and data reduction; unfortunately, such comparative costs are lacking for

these meters. Table VI-1 also summarizes the characteristics of some of the available meters insofar as such characteristics are known.

Table VI-1. Comparison of Prices, Depth Limits, and Speed Ranges of Various Current Instruments

Meter	Approx. Price	Depth limit (feet)	Speed Range (knots)	
			Min.	Max.
Roberts Radio Meter*	\$ 850	300	0.3	7.0
Ott Meter	1,890	150	0.06	10.0
Snodgrass Meter (Savonius Rotor plus direction sensor)	1,769	?	0.1	4.0
Savonius Rotor Current Meter*	500	None	0.05	3.5
Iwamiya Meter	306	650	?	?
Komatsu Meter*	680	Large	?	5.0
Ekman Meter*	430	None	0.1	1.5
Fjeldstad Meter	975	None	?	?
Dunkerque Meter	3,600	160	0.1	?
Hydrowerkstaten Paddle Wheel*	3,920	160	0.3	3.0
Electromagnetic Underwater Log*	3,500#	None	0.01	25.0
GEK*	3,300	Surface	?	?

\*Instrument owned by the Hydrographic Office

#Expected price after development

The greater fund of experience with the Roberts Meter in comparison with the other meters and the large variety of available accessories for it seem to make the Roberts Meter most suitable to the Hydrographic Office of all the meters investigated. However, considerable manhours

are required to reduce the taped chronograph recordings of the data output from the Roberts Meter to a summary of current speed and direction at various times.

#### D. RECENT INSTRUMENTS

Newer developments which show promise for wide-scale application to Hydrographic Office surveys are: (1) the various neutral buoyancy drifting acoustic sources and (2) the electromagnetic underwater log which is currently under investigation.

##### 1. Neutral buoyancy acoustic sources

The use of free-drifting acoustic sources that can be adjusted to hover at any depth and be tracked with hull-mounted hydrophones has interesting possibilities but at present appears prohibitively expensive except for very specialized applications. These units cost approximately \$200 each and are not recoverable.

##### 2. Electromagnetic underwater log

The U. S. Navy has underwritten the development of an underwater log that utilizes electromagnetic principles. The sensor is designed to measure flow with an accuracy of  $\pm 2$  percent and has a threshold value of 0.1 knot. It has potentialities as a current meter, but its conversion will involve considerable development.

##### 3. Savonius rotor current meter

This instrument has been developed recently for use in sensing ocean currents of very low drift. The estimated range of current measurements is 0.05 to 3.0 knots.

#### E. CONCLUSIONS AND RECOMMENDATIONS

Of the meters owned and/or tested by the Hydrographic Office, the most versatile is considered to be the Roberts Meter. At this Office a method has been developed and tested to feed the output from the Roberts Meter into a recorder which would print speed and direction directly onto a paper tape or other permanent form of recording or through an electric typewriter. Records in this form also are suitable for analysis by computers, and development of computer programming for such analysis is recommended. Further, improvements in calibration and mechanics should be pursued at the Hydrographic Office to try to obtain the maximum potential performance from the Roberts

Meter. Recent improvements in the contact mechanism are expected to prolong meter life, and fin and propeller configurations have been redesigned to reduce the threshold value. However, it is recommended that the standard procedures of current measurement, as now used in the field, be followed until improved methods of data analysis are fully developed, operational, and practical.

It will not be possible to adopt one instrument exclusively for all current measurements taken by the Hydrographic Office. Occasions will arise where only the unique characteristics of special instruments can adequately provide the required measurements. Therefore, it is recommended that the capability of the Hydrographic Office for measuring currents by using diversified principles be maintained and even expanded. However, it is felt that a large percentage of the required current observations can now be accomplished with the Roberts Meter and that future computer-input modifications will yield great savings in data analysis effort.

Other meters which show promise and may in time approach the versatility of the Roberts Meter are the Ott, Iwamiya, Dunkerque, and Snodgrass meters. The Hydrographic Office has plans for procuring two Iwamiya Meters. However, no immediate plans exist for evaluation of the Ott and Dunkerque meters. It is recommended that the Savonius rotor type meter (Snodgrass Meter) be investigated further for its possible incorporation into an ultimate data handling system and that one of these meters be purchased and evaluated by this Office.

In view of the high cost and nonrecoverability of neutral buoyancy acoustic sources, it is recommended that the Hydrographic Office not participate at this time in the development of this technique.

Several government agencies are pursuing the development of current meters, either through contracts or by use of their own facilities. Although these efforts are directed toward special-purpose current meters, it is expected that much progress also will be made toward the development of a general-purpose current meter. In view of these efforts by other agencies, it is recommended that the Hydrographic Office not undertake any development of the electromagnetic log at this time.

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## VII. OCEAN WAVE MEASUREMENTS

Pasquale DeLeonibus

### A. INTRODUCTION

Data on the properties of ocean waves are sought for a variety of reasons depending upon the needs of the user. Some of these reasons are: (1) To attack the problems associated with undersea warfare, such as the naval minefield, by studying the responses of various mines to actual sea conditions; (2) to obtain the "wave climatology" of a region by extended measurements (at least a year at one or more locations) of the wave systems in that region; (3) to check the correctness of the mathematical models which have been proposed to describe and explain the properties of ocean waves; (4) to study the eroding effect of waves on beaches and coasts so that better breakwater systems can be devised; and (5) to obtain basic information on what is probably the outstanding unsolved problem associated with the impulsive generation of the waves by wind: namely, the initial growth of very small wavelets (capillary waves).

The ocean surface wave system is composed of a spectrum of wave periods. By this is meant that the sea surface is made up of many individual sinusoidal components which combine to produce the complex ocean surface wave pattern. Since interest in waves may range from tiny capillary waves (whose wave lengths are of the order of centimeters) to mountainous waves (whose wave lengths are of the order of hundreds of feet), the required measuring instruments vary widely in their basic principles and designs. To complicate the wave measuring problem, in the open ocean the disturbance which is being measured disturbs the entire wave measuring system, so that it is very difficult to design a stable reference level which is at the same time a floating reference level. In order to provide a fixed reference level, wave measurements have been made by recording the changes in pressure which the wave system produces on the ocean bottom. In addition, surface wave measuring instruments have been mounted on piers, docks, and the so-called Texas Towers. However, since these structures are in relatively shallow water, the observations all include the distorting effect that the bottom has on the surface wave profile.

To measure the wave profile on the open ocean, floating and airborne instrumentation techniques have been devised with varying degrees of success. The Hydrographic Office made one of the earliest attempts to obtain such wave records by using a damped electric wave staff. In 1952 a pressure recorder-accelerometer unit was installed

and tested on the RRS 'DISCOVERY', the research ship of the National Institute of Oceanography. During the summer of 1953 the Hydrographic Office tested an accelerometer wave gauge mounted on the bow of a ship. The David Taylor Model Basin has successfully tested a raft-like instrument which works on the accelerometer principle. This instrument telemeters the data back to the ship and is expendable.

Airborne wave measuring techniques have been applied to several problems. One of these problems is the study of the directional properties of the wave spectrum by using photography. However, the work involved in interpreting the many aerial-stereo photographs is immense. Another problem is the study of glitter pattern photographs, as illustrated by the work of Cox and Munk. A glitter pattern is formed when the sun is reflected by the waves. By using aerial photographs, the glitter pattern can be analyzed to give the distribution of the slopes of the sea surface. Such knowledge provides an independent check on the proposed analytical forms of the wave spectra which have been advanced by Neumann, Roll and Fischer, Derbyshire, *et al.* The airborne altimeter measures wave heights by indicating the variation of altitude during level flight over the sea surface. This type of instrument is still in the developmental stage; a new model was tested by the Naval Research Laboratory during the spring of 1960, and a report on this instrument is expected in the fall of 1960.

Sometimes interest lies mainly in the study of the very low-frequency end of the wave spectrum. Tsunami waves are of this type of low frequency wave. They are practically indiscernible in the open ocean, but, because of their extreme wave length, they can be a hazard when they approach the shoreline and begin to feel bottom. Special recorders have been devised to eliminate the measurement of all but these long period waves in an attempt to provide a warning system.

The study of small capillary waves, which are artificially generated in the laboratory, requires delicate instrumentation. These waves also have been studied by photographic methods.

## B. DEFINITIONS OF TERMS

A few of the terms commonly associated with ocean wave instruments are presented below.

### 1. Bottom pressure fluctuation

This is the change in pressure at the sea bottom caused by the changing surface wave profile. Bottom pressure instruments can be

set so that sea level is recorded as zero pressure; thus, an increase in wave height increases the pressure, and a decrease in wave height decreases the pressure. A wave trace is obtained when these changes in pressure are recorded continuously. The wave trace may be studied to obtain its statistical properties by considering each individual wave. It also may be studied by considering it an example of a time series, and the energy spectrum of the wave profile can be obtained by an electronic analyzer or a high-speed digital computer.

## 2. Accelerometer

This is a device which is used on some oceanographic instruments to measure the vertical component of acceleration that the sea surface imparts to an object floating on it. Since the vertical displacement of the object usually is required, the output must be integrated twice.

## 3. Capacitance-type wave gauge

This is a gauge which utilizes the principle that the capacitance of a rod varies as the depth of immersion is varied. For example, a dielectric-coated metal rod when placed in water acts as a variable capacity to the water, the capacity being linearly dependent upon the depth of immersion providing that the coating is uniform. A continuous measurement of the changes in capacity provides the wave-form of any disturbance on the water surface as it passes the rod.

## 4. Resistance-type wave gauge

This type of gauge utilizes the principle that the resistance of a rod varies as the depth of immersion. For example, the step-resistance gauge consists of a series of exposed electrodes mounted vertically on a staff. As the wave passes and covers more electrodes, the total gauge resistance decreases. Thus, measurement of the wave-form is reduced to the measurement of a varying resistance. Some gauges use a continuous length of wire as the sensing element, but the principle remains the same.

# C. INSTRUMENT TYPES

Three types of wave measuring instruments are discussed in this section: bottom pressure instruments, floating wave gauges, and fixed wave gauges. A few instruments are discussed in detail, whereas others are described briefly; still others merely are cited in the literature. Many types of wave measuring instruments are in use,

but the basic principles of many of them (in each category) are similar. For example, the principles of the step-resistance gauge developed by the Beach Erosion Board have been used in the construction of fixed wave gauges of all sizes. The transducers of bottom pressure gauges are usually strain gauges or Bourdon tubes. Most of the instruments described below are used to obtain data on a routine basis. No laboratory wave gauges are discussed, nor any stereo-photographic techniques; however, references on both of these instrumentation techniques are given at the end of this Section.

### 1. Bottom pressure instruments

#### a. Wiancko pressure measuring system

This pressure measuring system was designed by the U. S. Navy Mine Defense Laboratory to measure and record water pressure changes of 0.1 inch to 80.0 inches to a depth of 200 feet. As much as 12,500 feet of type WF8/G cable may be used if certain precautions are observed. The pressure measuring system includes three basic units which are shown in Figure VII-1. The underwater unit consists of a differential pressure gauge in a housing which also contains a hydraulic filter to compensate for static pressures and a calibration relay circuit. The differential pressure gauge produces an electrical signal which is proportional to the pressure variation by changing the ratio of two inductances. The electronic unit contains two resistances which complete a bridge circuit with the two inductances and produce a d.c. voltage proportional to the pressure variations. The recording unit is a recording milliammeter which serves as the indicating device for the pressure variation.

The calibration is accomplished by paralleling one leg of the gauge coil with a capacitor which will unbalance the bridge the same amount as would 32 inches of water pressure change. The a.c. bridge current is provided by a 3,000 c.p.s. oscillator in the electronic unit. The bridge is operated at a point of deliberate unbalance, but the electronic unit is arranged to subtract off a signal voltage equal to that caused by the normal amount of deliberate unbalance; therefore, meter deflections are proportional to changes from this normal degree of unbalance. (See Reference VII-30.)

#### b. Acoustic system Mark I, Mod 4

The acoustic system Mark I, Mod 4, designed by the Naval Ordnance Laboratory, measures and records very low-frequency sounds from the low audio ranges down to static pressures. The pressure-

ELECTRONIC UNIT

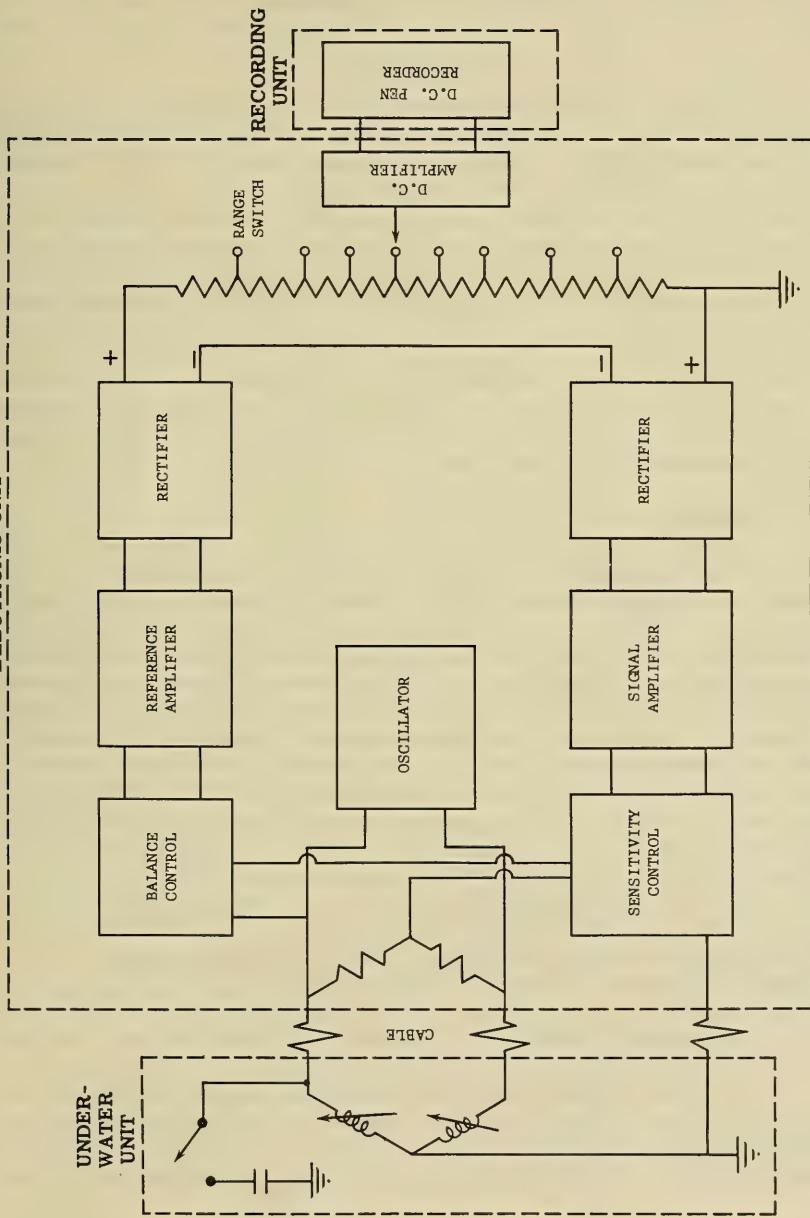


Figure VII-1 Wiancko Pressure Measuring System

sensitive element of this system is essentially an inductance which is varied by changes in pressure and is contained in one arm of an a.c. bridge located on shore. The bridge is driven by a 1,000 c.p.s. oscillator that has good amplitude and frequency stability.

An incremental change in pressure applied to the pressure-sensitive element varies the a.c. output of the bridge. This output is combined with an additional output from the balancing network, and after amplification the combined output is demodulated. The output from the demodulator is filtered and appears as a voltage that varies in accordance with the pressure changes on the underwater element. Frequencies below 1.5 c.p.s., after amplification by a d.c. amplifier, are recorded on a milliammeter. This meter also is used to determine the state of balance of the bridge.

The acoustic system Mark I, Mod 4 can operate to a depth of 200 feet and use cable lengths as much as several miles. This system has been used extensively to obtain wave records over long periods of time off several shorebased stations.

c. Mark IX shore wave recorder

The Mark IX was designed at the University of California as a general purpose instrument for permanent installation. The principal component is a differential pressure potentiometer, which is used as the transducer. The movement of a pressure-sensitive brass bellows is magnified by a potentiometer contact lever which, in the normal position of zero differential pressure, divides the resistance of the potentiometer windings equally. Variations of differential pressure cause the potentiometer contact arm to move across the windings. The position variation of the potentiometer arm is converted to a proportional current by the bridge circuit and recorded. The low impedance (750 ohms) and high power dissipation (one watt) of the transducer potentiometer enable the pressure head to be used with practically any type of recorder available. In this case, an Esterline-Angus recording milliammeter connected into a 24-volt Wheatstone bridge circuit, of which the pressure head forms two legs, is used as a standard recording system. (See Reference VII-22.)

d. Shorebased recorder of low-frequency ocean waves (abstract)

This instrument has a pressure head on the sea bottom that contains a hydraulic filter. The filter attenuates high-frequency signals caused by ordinary gravity waves and very low-frequency signals caused by tides. The maximum response is for frequencies of about

one cycle per 1,000 seconds. A strain-gauge transducer converts the filtered pressure fluctuations into electrical signals, which are transmitted to shore through a cable.

Sea pressure is transmitted through a rubber bellows (Figure VII-2). Two capillary tubes,  $R_1$  and  $R_2$ , lead to two domes that contain metal bellows,  $C_1$  and  $C_2$ . The rubber bellows, capillary tubing, and the compliant chambers between the domes and the exteriors of the metal bellows are filled with silicone fluid. The interiors of the two metal bellows and the transducer chamber are filled with air maintained at atmospheric pressure. The total air reservoir is large relative to the volume of the metal bellows, and the variation in air pressure due to the deflection of the bellows is negligible compared to the changes in outside pressure. The transducer chamber and the interiors of the metal bellows can be pressurized to extend the depth of installation, which is otherwise limited by the bellows to ten meters (one bar).

Two identical bellows are used in the compliant chambers, but the capillary tubes are adjusted so that their resistances to the flow of hydraulic fluid have a ratio of about four to one. A strain-gauge pressure transducer is connected between the two compliant chambers to sense the differences in pressure. Because of the flow resistance of the capillary tubing, high-frequency pressure fluctuations (ordinary gravity waves) cause negligible pressure changes within the compliant chambers and between them. For very low-frequency pressure fluctuations (tides), the pressure in each chamber essentially equals the applied pressure, and the pressure difference between the chambers is again negligible. For intermediate frequencies the pressures in the two chambers are unequal owing to the difference in resistance of the capillary tubes, and an appreciable signal will be produced by the transducer. (See Reference VII-23.)

#### e. Knapp bottom pressure gauge (abstract)

This bottom pressure gauge was designed for studying harbor surging and developed and tested at the U.S. Naval Station, Long Beach, California. A strain-gauge unit, used in connection with a pressure-sensitive bellows, comprises the transducer of the pressure head. The four strain-gages in the unit are connected to form a bridge circuit that is linked to the recorder by an electrical cable. A d.c. voltage is applied to the bridge, and the record is obtained by recording photographically the unbalanced current from a magnetic oscillograph. Any standard strain-gauge recorder can be used for the recording system.

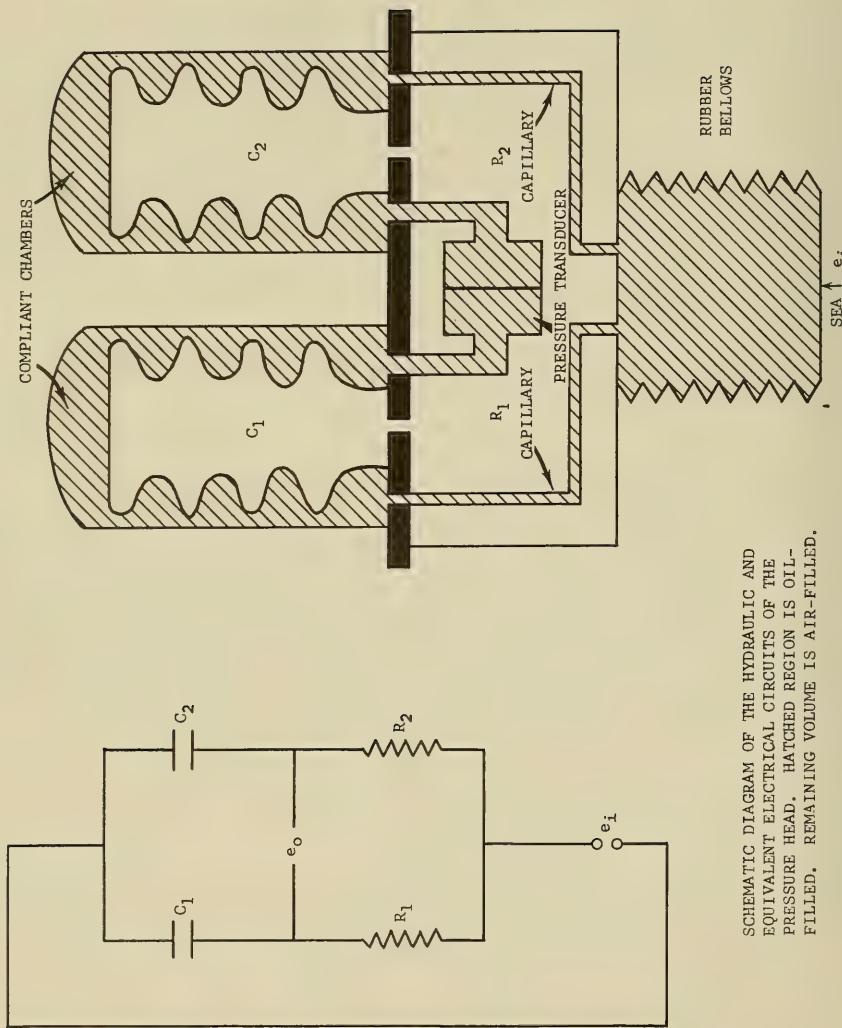


Figure VII-2. Shorebased Recorder of Low-Frequency Ocean Waves

The gauge differs from other pressure gauges in that no slow leak is provided to eliminate tides and long period waves. In place of the slow leak, a solenoid valve is installed which is held open while the instrument is being lowered or raised to prevent damage to the pressure-sensing element. Once the instrument is in place, the valve is closed electrically to seal the reference chamber at an average pressure corresponding to the depth of the water. (See Reference VII-16.)

f. Mark VI shore wave recorder (abstract)

The Mark VI shore wave recorder was designed to fulfill the need for an instrument with a high frequency response to record subsurface pressure fluctuations in the surf zone. High frequency response is obtained by using a Brush universal strain analyzer that has a uniform frequency response to 100 cycles per second and an underwater pressure head with a correspondingly high natural frequency. (See Reference VII-24.)

2. Floating wave gauges

a. Electric wave staff

This instrument, developed by the Hydrographic Office, consists of three water-tight sections of three-inch diameter, 12-foot long aluminum tubing, coupled together with one-inch threaded pipe to form a 36-foot long staff. Below this, at a distance of 20 feet, is suspended a three-foot diameter, corrugated, metal damping disk. The staff and disk are weighted so that the staff floats vertically with six feet of length exposed in calm water; thus, the effective measuring length of the staff is 12 feet. However, the vertical motion of the staff is such that under certain wave frequency conditions, waves as much as 20 feet in height can be measured. A step-resistance gauge is mounted on the upper 12-foot section of the staff and consists of a series of 36 contact points spaced four inches apart. This gauge is similar to the type developed by the Beach Erosion Board. (See Part C,3,a of this Section.) Inside the staff and between each contact stem is placed an appropriate resistance in series. As a wave rises up the staff, submerging additional contact points, proportionately more current flows through the circuit as the parallel salt water current path reduces the resistance of the gauge. The upper 12-foot section of the staff containing the electrical circuit is coated with neoprene rubber. This causes water to drain off the surface of the staff rapidly when a wave has passed and prevents current leakage.

The shipboard equipment consists of a transformer; rectifier and filter; and a single-channel, magnetic pen recorder.

A calibration curve is necessary to convert apparent wave heights to true wave heights. This is necessary because the wave staff has its own vertical motion relative to the wave motion. (See Reference VII-32.)

Although the wave staff is difficult to operate in rough weather, it operates satisfactorily in moderate weather. Generally, however, it is difficult to keep a ship from imparting some of its motion to the floating instrument through the cables linking the wave staff to the on-deck equipment.

b. Floating accelerometer on a raft

This recorder was developed by Dorresteijn at the Dutch Meteorological Institute for measuring waves in the open sea (Reference VII-6). It utilizes an accelerometer placed on a small raft which is connected with a ship by a conducting cable. The accelerometer supplies a signal which corresponds essentially to the vertical acceleration of the sea surface. This signal is integrated twice, and the integrated recording is made aboard ship. The frequency response is constant to periods as small as 1.5 seconds. The recorder has some of the disadvantages of the wave staff in that it is a floating instrument and tends to float away with the current. The advantages are that it is relatively small and can be handled by two men, its weight being about 45 pounds. This instrument provided the basic idea for the instrument developed by the David Taylor Model Basin.

c. Telemetering wave buoy (splashnik)

The wave buoy, developed at the David Taylor Model Basin, is similar to the device developed at the Dutch Meteorological Institute. However, one significant difference is that this unit transmits its vertical acceleration signals back to a ship by radio, eliminating any ship motion from being imparted to the buoy. The system consists of a buoy assembly containing a transducer and transmitter, a wide-band FM receiver, an electronic low-pass filter, and a recorder. The transmitter sends a signal that varies in frequency proportional to the acceleration experienced by the buoy assembly. This signal is received by an antenna mounted on a ship and is fed into the FM receiver. In the receiver the frequency changes are converted to a varying d.c. voltage which is proportional to the acceleration. The d.c. voltage is placed on the input of the adjustable low-pass filter which cuts off the signals produced by the surface chop of the sea,

but passes unaltered the lower-frequency signals produced by the larger and longer waves. The output of the filter unit then is recorded either on magnetic tape or on a direct-writing recorder. The surface wave record is obtained by a double integration of this output. (See Reference VII-29.)

This wave buoy was not designed to be a refined instrument; the cost has been kept at around \$100 to \$200, and it probably could be brought lower by mass production. Thus the buoy can be considered as expendable if necessary. The transmitter is subject to some frequency drift, and the tuner needs occasional retuning. An error exists in the acceleration information obtained, because the lever arm of the accelerometer does not remain horizontal as the float assembly rides up and down the waves.

d. Inductance-type and capacitance-type wave poles

These two wave poles were developed at the Woods Hole Oceanographic Institution and are similar in general operation to the electric wave staff of the Hydrographic Office (Reference VII-8). One pole is a capacitance type; the other is an inductance type. The two poles differ from the one used at the Hydrographic Office in that no damping disc is required; damping is attained by flooding tanks which are component parts of the poles. The capacitance pole radios data back to a ship, but the inductance pole requires a connecting cable. Both poles resonate at 38 seconds; however, some undesirable bouncing occurs at around 19 seconds. These two poles seldom are used except in fairly calm seas. At the Woods Hole Oceanographic Institution, the Tucker accelerometer (see below) has been installed on the ATLANTIS, and this instrument is used in preference to the two wave poles.

e. Ship-borne wave recorder

This instrument, designed by Tucker at the National Institute of Oceanography, measures waves directly aboard ship. It combines the sea pressure at a point on the hull of the ship with the vertical displacement of this point which is obtained by double integration of the output of a vertical accelerometer. No equipment has to be put outboard. This instrument has been tested by taking 2,500 wave records and has proven fairly satisfactory. However, the extremely uncertain response of the system to wave periods of less than seven seconds is a disadvantage. (See Reference VII-27.)

#### f. Submarine wave recorder

One of the most recent developments in the field of oceanographic instrumentation is the use of a submarine as a hovering, submerged, stable platform from which to measure oceanographic variables. The Hydrographic Office has recently conducted tests with the Westinghouse sonic surface scanner which is essentially an inverted echo sounder mounted on the deck of a hovering submerged submarine. The travel time required for the vertical sound beam to go from the submarine to the sea surface and return (in a 3°-cone) is proportional to the height of the water above the submarine. Thus, changes in water height above the submarine are recorded as changing wave height.

The manufacturer claims the surface sonic scanner can detect changes in surface wave height to the nearest foot when the submarine is submerged at a depth of about 100 feet. This assumes that the amplitude of the submarine roll is small at a depth of 100 feet, which is usually the case, except when extremely rough conditions occur at the surface. The Hydrographic Office currently is analyzing and evaluating data taken with the sonic scanner by computing power spectra with a high speed digital computer.

### 3. Fixed wave gauges

#### a. Beach Erosion Board step-resistance gauge (abstract)

This gauge (the prototype of the resistance wire wave staff) utilizes a 25-foot length of sealed pipe which houses a series of electrical contact points spaced at intervals of 0.2 foot. The contact points (made from spark plugs) are connected to a resistance circuit within the pipe. The gauge is mounted vertically on a supporting structure, such as a pier, and the bottom of gauge is set below the lowest expected wave trough; the top of the gauge must be above the highest expected wave crest. The exposed tips of the plugs are covered with lead to reduce corrosion effects. In order to overcome the short-circuiting effects of the sea water film which adheres after a wave passes, the gauge pipe and the bases of the spark plugs are covered with neoprene.

A constant voltage, 115-volt, a.c. transformer supplies power to the gauge; its primary is connected through a timing switch to provide automatic programming. Alternating current is supplied to prevent polarization and is converted (through a selenium bridge rectifier) to a proportional d.c. current, which in turn drives the recording unit.

mechanism. A magnetic pen recorder is used which has a high frequency response and can record waves with periods as small as one second.

The values of the resistors connected to the contact points of the gauge are adjusted so that the variation in the current is proportional to the submerged length of the gauge. By recording the variation of the gauge current, a record of the rise and fall of the sea surface is obtained which includes tide variations as well as wave action. (See References VII-1 and VII-2.)

Two types of gauges have been built and used by the Beach Erosion Board. One is a series-type step-resistance gauge and the other a parallel-type.

#### (1) Series-type step-resistance gauge

In this type of gauge, the resistors are connected in a series circuit, and the junctions between resistors are tied to the contact points. As the sea surface rises, the water shorts all resistors tied to submerged contact points and causes an increase in current proportional to the number of contacts below the surface.

#### (2) Parallel-type step-resistance gauge

In this type of gauge, one end of each resistor is connected to a spark plug, the other end to the gauge voltage supply. The sea provides a current path between the contact points and a ground rod connected to the other side of the voltage source. As the spark plugs are submerged, the resistors are added in parallel. The values of these resistors are so selected that the current flowing in the circuit is proportional to the number of contact points submerged. The parallel-type step-resistance gauge is not as seriously affected by the accumulation of water film as is the series type, because its resistance values are small compared to the resistance of the water film.

### b. Electronic sea-wave recorder (abstract)

This instrument is a surface type of sea-wave recorder which is based upon the principle that the capacitance between sea water and an insulated wire placed vertically in it varies with changes in the level of the water. This change in capacitance is used to modulate the frequency of an oscillator. An electronic unit is used for recovering from the frequency modulated signal an electrical voltage which is an exact replica of the sea wave. (See Reference VII-18.)

The advantages of this recorder are: (1) It is suitable for both laboratory studies and sea-wave recordings; (2) this type of recorder responds well to waves of all frequencies and can follow the rise and fall of the water surface with negligible error; and (3) the performance of the capacitance-wire electrode is fairly reliable and comparatively free from the action of the sea water.

#### c. Resistance wire wave staff

This instrument was built for the Hydrographic Office by the Atlantic Research Corporation. The component parts, shown in Figure VII-3, consist of an oscillator, a vacuum tube voltmeter, a recording milliammeter, and a continuous length of Chromel wire which is strung through a telescopic stainless steel tube. The resistance of the Chromel wire changes linearly as the sea water moves up and down its length. A full scale deflection equivalent to 15 feet of wave height is possible on the recorder.

Since the diameter of the wire is small, the sea water tends to drain off rapidly as the trough of a wave passes the gauge. Thus, the "wetting" problem which has troubled the operation of other fixed wave gauges in the past is overcome. This instrument is in successful use by the Hydrographic Office on one of the Texas Towers.

### D. CONCLUSIONS AND RECOMMENDATIONS

Ocean surface waves may vary from very short capillary waves (ripples) to very long tsunamis (waves generated by submarine earthquakes). Of great practical importance to the Hydrographic Office are those wave groups whose periods range from 1 to 30 seconds. This Office currently is investigating the properties of such waves by measuring them with bottom pressure recorders, floating measuring devices, fixed wave staffs, and air-borne instruments; such data are useful to the study of undersea warfare problems. Further wave data also are required to study the behavior of undersea weapons and to check the theories that are used in wave forecasting. Some of the instruments described in this Section are in active use whereas others are still in the test and developmental stages.

#### 1. Bottom pressure instruments

Of the various bottom pressure wave recorders that have been discussed in this Section, the Wiancko pressure measuring system, the Mark I, Mod 4 acoustic system, and the Mark IX shore wave recorder all have stood the test of time. Of these three instrument

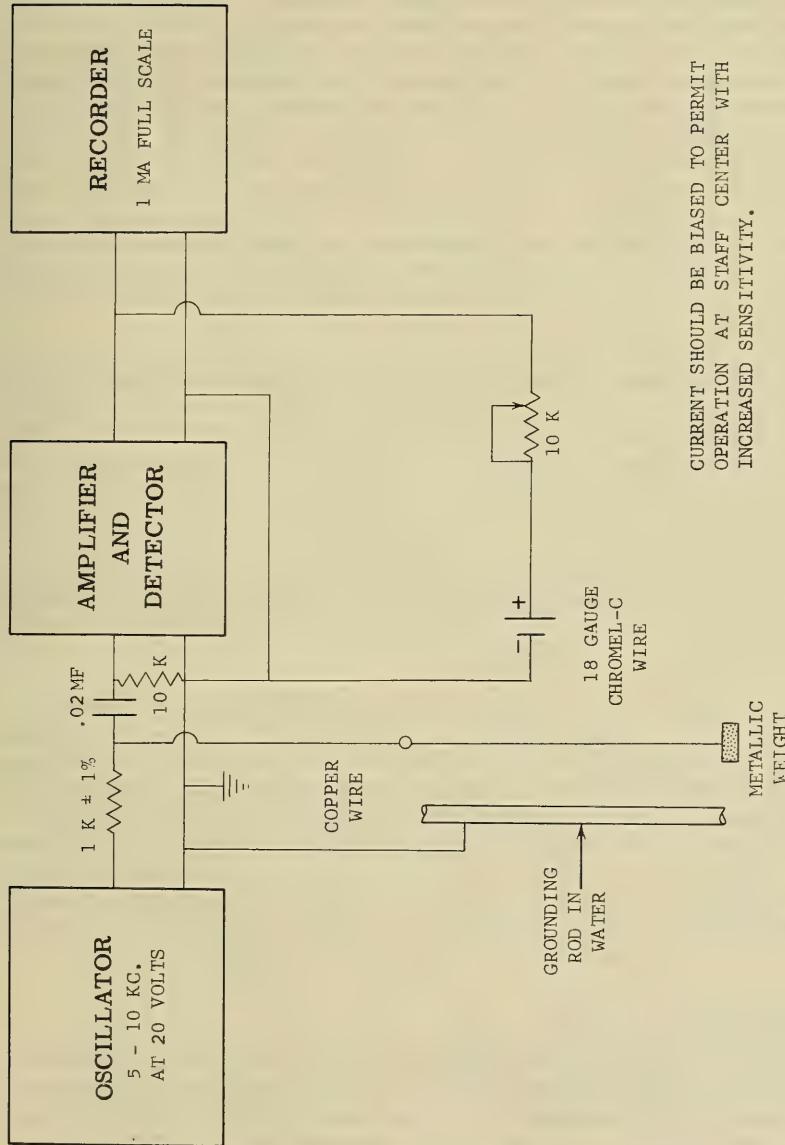


Figure VII-3. Resistance Wire Wave Staff (Prototype)

systems, the Wiancko system is considered somewhat more adaptable and versatile than the others, since it is light and compact and can be used from an anchored ship. It can be lowered to and raised from the sea bottom by hand if the depth is not too great, whereas both the acoustic system and the Mark IX require major placement operations and become increasingly difficult to install as the water depth increases. The three systems have been operated satisfactorily at depths of 50 to 75 feet, and all are capable of operation at depths of 30 to 200 feet.

All three systems are fairly easy to calibrate and operate. The Wiancko, for example, can be operated at a very high sensitivity; a full-scale deflection can be obtained for one inch of water. However, it operates best at full-scale deflections equal to or greater than five inches of water.

The acoustic system has been operated for two years, and the Mark IX has been operated satisfactorily for periods of three months without requiring recovery from the bottom. The Wiancko system has not been tested for long periods of immersion, but such tests are now being made at Fort Story, Virginia. It is recommended that these tests continue to determine the total time that this system can be operated without recovery and overhaul.

The Wiancko system and the Mark IX are about equal in cost and do not require elaborate or unusual instrumentation. The acoustic system, however, requires a comparatively expensive initial outlay but may have an overall longer life.

The acoustic system is being improved continuously: The balancing system is better, and the inclusion of a tide leak has given the system a greater sensitivity. An improved model of the acoustic system is being used by the Hydrographic Office at Fort Story, Virginia for a detailed study of wave conditions on the East Coast. Further improvements in the entire system, particularly in the bridge network, are being continued. It is felt, however, that at the present time the Wiancko system is more suitable for use by the Hydrographic Office for short-term, shipboard operations because of its ease in handling, installation, operation, and maintenance, and its moderate cost.

## 2. Floating wave gauges

The smallness of size and telemetering feature make the telemetering wave buoy (splashnik) preferable to long wave poles and any wave measuring instruments that must be tethered to a ship by a conducting cable. It is considered that the wave buoy also is probably a

definite improvement over the ship-borne wave recorder in that it should respond to much lower-period waves because of the smaller size of the buoy compared with that of a ship. Although a certain amount of error exists in the acceleration information received, and the transmitter and tuner are not completely drift-free, the Hydrographic Office has purchased several of the telemetering wave buoys for obtaining wave records in the open sea. It is recommended that, in addition to further accuracy tests, extensive tests be made to determine the number of times the telemetering wave buoy can be launched and recovered without breakdown.

At the present time the submarine sonic scanner offers the best, if not the only, opportunity to obtain accurate wave records in deep water over the complete wind-wave spectrum of interest.

### 3. Fixed wave gauges

It is felt that the resistance wire wave staff overcomes the accuracy problems inherent in the several step-resistance gauges discussed in this Section and is simpler to construct than the electronic sea-wave recorder. Therefore, it is recommended that use of this gauge be continued and that additional gauges be built for installation at other locations. An improved method of analysis of the wave data should be devised to facilitate the processing of the information derived from these gauges.

## E. SELECTED REFERENCES

The references listed alphabetically below also may be grouped into various categories for convenience and ease in pursuing a particular subject as follows: (1) collected references, (2) bottom pressure instruments, (3) floating wave gauges, (4) fixed wave gauges, and (5) airborne wave measuring techniques.

### 1. Collected references

References VII-2, -4, -10, -11, -15, -22, -28, -33, and -36 on various subjects are collected in Proceedings of the First Conference on Coastal Engineering Instruments, Berkeley, California, October 31 - November 2, 1955, edited by R. L. Wiegel, and published in 1956 by the Council on Wave Research, The Engineering Foundation. References VII-21 and VII-31 contain short discussions of various bottom and

floating gauges. References VII-14 and VII-26 contain discussions of some bottom, floating, and fixed gauges not covered in this Section; in addition, Reference VII-14 contains a discussion of the Sonne three dimensional aircraft camera.

## 2. Bottom pressure instruments

Various bottom pressure instruments are discussed by References VII-12, -13, -14, -16, -20, -21, -22, -23, -24, -25, -26, -30, -31, and -34.

## 3. Floating wave gauges

Part C,2 of this Section discusses and references several floating wave gauges. These gauges are covered in greater detail by References VII-6, -8, -27, -29, and -32. References VII-14, -21, -26, and -31 also contain articles on various floating gauges.

## 4. Fixed wave gauges

Part C,3 of this Section briefly discusses several fixed wave gauges. These and other gauges are discussed in greater detail by References VII-1, -2, -3, -7, -9, -14, -17, -18, -26, and -35. No published information is available for the resistance wire wave staff of the Hydrographic Office.

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## VIII. RADIATION MEASUREMENTS

Robert B. Elder

### A. INTRODUCTION

Radiation studies are made for a number of purposes. The type of instrumentation used for any radiation study depends a great deal upon the purpose of the study. In physical oceanography, radiation studies have a twofold purpose. From these studies the rate can be determined at which radiant energy from the sun and sky is absorbed and converted into heat in the upper layers of the sea. This determination is a principal factor in the computation and prediction of thermal structure changes. Secondly, the extinction coefficients determined by underwater measurements give information concerning the optical purity of the water and the amount of suspended matter.

The parameters to be measured in a heat budget study include the incoming and reflected radiation at the sea surface and the attenuation and scattering beneath the surface. These parameters are a function of the angle of the sun, the sea state, the turbidity of the atmosphere and water, and the distribution of energy in the solar spectrum and its differential absorption.

The physical factors which influence the visual detectability of submerged objects have been an important subject of study for some time. In this case it is important to know the optical principles which govern the transmission of an image through water. Many factors combine to govern the visual detectability of submerged objects to an observer below or above the surface. Detection of objects by an observer either below or above the surface requires that the reflectivity or the color of the object differ sufficiently from that of its background, so that the optical signal reaching an observer exceeds his contrast threshold despite attenuation by the intervening water. Other factors which affect the contrast of an object viewed from above the surface include the same parameters that have been indicated for heat budget considerations. However, sea state becomes more important than the others when detection through the surface is attempted. Although the amplitude of the waves is of little importance in optical studies, the slope of the water surface determines the reflective and refractive effects. An observer looking through a wind-roughened surface receives his images from changing angles because of the rapid and random changes in wave slope.

Light is also important in biological studies, in that it provides the primary energy source for food production by photosynthesis. However, radiation studies as applied to biology have not been considered to relate very much to fulfilling the purpose of the Hydrographic Office.

## B. INSTRUMENTATION

Although methods of measuring radiation have not been standardized, several basic types of instruments are in common use. These are used either above or below water. Instruments representative of the basic types are described below.

### 1. Instruments used above water

#### a. Eppley pyrheliometer

This instrument is designed primarily for measurement of the intensity of solar radiation upon a horizontal plane and is calibrated at the Eppley Laboratory in sunshine against pyrheliometers which are standardized every year at the Weather Bureau, Washington, D. C. The probable error for the instrument, as compared with direct radiation intensities ranging from 0.25 to 1.50 gm cal/cm<sup>2</sup>/min., is  $\pm 1.5$  percent. The instrument is sensitive to the wavelength range between 3,000 and 50,000 Å.

Two types of pyrheliometers are available. One has ten junctions for use with recorders having a range of zero to four millivolts, and the other has 50 junctions for use with recorders having a range of zero to 16 millivolts. The price of a 50-junction type Eppley pyrheliometer mounted on a chromium plated base is about \$300.

#### 2. Geir and Dunkle radiometer

The response of the Geir and Dunkle radiometer is independent of the wave length of the incident energy. For this reason this instrument has an advantage over a pyrheliometer in that it can be used to measure long wave radiation as well as solar radiation and can be used both for daytime and nighttime measurements. It also can be used as a net exchange radiometer to measure the net heat transfer through a surface.

The radiometer is essentially a heat flow meter and consists of three bakelite plates 4 1/2 inches square and 1/64 inch thick. The thermopile is constructed by winding 40-gauge constantan wire onto

the center plate at approximately 88 turns per inch. The wire is then silver-coated on one side of the plate, giving in effect a series of thermocouple junctions on opposite sides of the plate.

Aluminum cover plates are mounted on both sides of the thermopile. These plates increase the thermal capacity without appreciably increasing the thermal resistance, thereby damping out minor variations in heat flow caused by fluctuations in the air stream. The cover plates also give additional strength and weather resistance. The upper aluminum plate is painted black to absorb the incident radiation, and the lower aluminum plate is highly polished to reduce the emissivity and absorbtivity to the lowest possible values. When the instrument is used as a net exchange radiometer, both the upper and lower aluminum plates are painted black.

Since long wave radiation will not penetrate glass, no protective coverings are put over the sensitive surfaces. The sensing unit is mounted in the air stream from a small blower to maintain uniform values of the unit thermal resistance from both meter surfaces. The air stream also prevents the deposit of dust or dew on the meter surface.

The correlation between radiometer and pyrheliometer readings is reportedly high. When the radiometer and pyrheliometer are used together, and since the pyrheliometer is sensitive only to short wave radiation, the long and short wave components can be separated from the total radiation by subtracting the pyrheliometer reading from the radiometer reading.

The use of the radiometer at sea remains to be proven. Past attempts at use have resulted in erratic readings which are believed caused by irregular winds striking the sensitive surface. Sea spray and salt deposits on the sensitive surface likewise change the calibration from time to time.

The Geir and Dunkle radiometer has been used over fresh water and snow and in dusty areas with a high degree of dependability and has required minimum maintenance over prolonged periods.

## 2. Instruments used under water

### a. Secchi disc

The Secchi disc probably has been the most widely used device for measuring the clarity of ocean waters. It consists of a

horizontal white or black disc that in operation is lowered into the water to the greatest depth at which the disc is visually detectable. Drawbacks of a Secchi disc observation are that it depends upon a number of variable factors: the eyesight of the observer, sea state, accuracy of the line markings, whether the disc is in sun or shadows, etc. Therefore, a Secchi disc reading unsupported by other evidence cannot be interpreted in terms of the more fundamental optical constants. It gives only an approximate index of the transparency of the surface layers.

b. Water clarity meter (movable disc type)

This water clarity meter is a visual photometer that overcomes some of the disadvantages of the Secchi disc. The instrument consists of two discs of different colors and sizes connected by a vertical shaft. The upper (gray, smaller) disc slides on the shaft so that it can be lifted above the fixed, lower (white, larger) disc by an auxiliary line. The upper disc is separated from the lower disc until the two appear to be equally luminous. Once the two are properly separated they will continue to match in homogeneous water regardless of the depth to which the apparatus is submerged.

The separation of the discs is a direct measure of the clarity of the water and can be converted to hydrological range by a multiplying factor. The hydrological range is that range at which the apparent contrast is two percent; the apparent contrast is a function of the reflectivities of the two discs, their average depth, and the angle of sight to the discs. This device was developed a number of years ago, and it is believed to have received very little use.

c. Barrier layer cell

For ambient light measurements in the upper 50 to 100 meters a barrier-layer-type cell generally is used. One of the better known types is the Weston photronic cell. It responds to light wave lengths between 3,000 and 7,500 Å with a maximum response around 5,500 Å. With the proper detection device this cell has sufficient sensitivity to measure radiation of as little as  $10^{-4}$  gm cal/cm<sup>2</sup>/min.

Filters generally are used in conjunction with barrier layer cells. However, the total radiant energy between 3,800 and 7,120 Å can be determined with filterless barrier layer cells by using the proper factor. This factor is a function of the depth of measurement and ratio of the amount of subsurface radiation to the surface radiation.

#### d. Photomultiplier tube

Barrier layer cells have insufficient sensitivity for measuring ambient light at depths greater than 200 meters even in the clearest water. However, photomultiplier-type photometers are sufficiently sensitive to measure illumination as little as  $10^{-12}$  gm cal/cm<sup>2</sup>/min. and thus can be used to a depth of 500 to 600 meters. It is necessary to use some type of shielding device when using a photomultiplier tube in illumination greater than  $5 \times 10^{-5}$  gm cal/cm<sup>2</sup>/min., and a neutral filter of density 4 is necessary if the instrument is to be used at the surface.

A photomultiplier tube is more sensitive to short wave lengths than is a barrier layer cell. Its peak sensitivity is around 4,500 Å. In deep water it should be necessary to use only a blue-green filter; however, an automatic filter changing device has been developed.

Although it is remarkably sensitive, a photomultiplier tube, has a number of disadvantages. The tube requires a high input-voltage in the order of 1,000 volts and produces a signal current which ranges from .01 microampere to one milliampere. The output at constant light level is strongly dependent upon the supply-voltage, so that a well regulated power source is necessary. The signal at constant light level and constant voltage is also a function of the orientation of the tube in the magnetic field of the earth; hence the tube requires magnetic shielding.

#### e. Dual-filter hydrophotometer

This instrument was developed by the Chesapeake Bay Institute. It is capable of giving in situ readings of two wave lengths within the visible part of the spectrum. Measurements can be made at day or night.

Essentially the instrument consists of a constant light source placed at a set distance of 15 centimeters from two photocells, each one fronted by a suitable filter. The electrical output is proportional to the amount of light striking each photocell and, therefore, is a function of the transparency of the medium.

The underwater unit contains a six- to eight-volt sealed beam spotlight unit and the two photocells. The spotlight is an automobile type, having an angular spread of approximately four degrees. General Electric type PV-10 photocells are used. The filters are type B.G.-12 for blue and type R.G.-1 for red.

An arrangement is made to filter out most of the daylight which would interfere with the transparency measurements by a honeycomb of blackened drinking straws being placed between the photocells and the filters.

f. Tri-filter hydrophotometer

This hydrophotometer is basically identical to the dual-filter hydrophotometer. It is, however, lighter and easier to maintain. The electrical circuit has been redesigned to simplify operation and provide better linearity. In addition to the blue and red filters on the dual-filter hydrophotometer, a green filter is used on the tri-filter hydrophotometer. This instrument is designed for use in turbid estuarine and coastal regions and is not considered suitable for deep water transparency measurements.

g. Clarke bathyphotometer

Two basic elements comprise the Clarke bathyphotometer: the submerged unit carrying the photomultiplier tube and the depth meter sensing element, and a deck unit consisting of a high voltage supply, the depth meter indicator, and a vacuum tube microammeter. Supplementary equipment includes an oscillograph amplifier, a recorder on which flashes of light from luminescent fishes can be recorded, and a field calibration unit.

The spectral sensitivity of the instrument extends approximately from 3,200 to 6,500 Å with a maximum at 4,800 Å. Illumination as low as  $10^{-11}$  gm cal/cm<sup>2</sup>/min. and depths as great as 610 meters can be read directly on deck.

h. Water clarity meter (photocell type)

This meter, developed by the Visibility Laboratory of the Scripps Institution of Oceanography, was designed to permit determination of underwater visibility by swimmers. It will measure and record surface illumination, the decrease of ambient light with depth, the attenuation of a beam of light beneath the surface, and the depth of the instrument.

The underwater unit consists of an Alpha-meter which is a light source at a fixed distance from a photocell to provide a measure of the attenuation of a beam of light, an h-meter which is a photocell to measure the ambient light, and a pressure transducer. The spectral

response of the photocells is made similar to the response of the average human eye by means of special filters on each cell.

The deck unit consists of a photocell for measuring surface illumination, an electronic unit, and a recorder. Any of the four parameters may be recorded separately, or each may be recorded in succession by an automatic sequencing arrangement.

This water clarity meter has a number of limitations. Like all optical equipment it is easily knocked out of alignment. However, good instructions are provided for the instrument, and it is easy to realign. The vertical distance between the h-meter and the Alpha-meter light path, approximately two feet, makes correlation between the two meters rather difficult. The error of the Alpha-meter is approximately two percent. Good results can be obtained with this instrument when it is used by highly trained oceanographers. It is not, therefore, recommended for use as a standard survey instrument.

## C. CONCLUSIONS AND RECOMMENDATIONS

With the growing importance of heat budget and thermal structure studies required for sonar forecasting, an urgent need exists to measure and predict the radiant heat exchange through the sea surface and the distribution of heat with depth. It follows then that the development of adequate radiation measuring instruments is a necessity.

### 1. Instruments used above water

#### a. Geir and Dunkle radiometer

The measurement of long wave radiation, to a large extent, has been neglected in the field of oceanography. The Geir and Dunkle type radiometer has been used successfully in measuring long wave radiation over land, over snow, and over fresh water. The modification of this instrument as an oceanographic tool should be investigated. Of the radiometers investigated, this instrument appears to offer the best promise for a seagoing instrument that will measure both daytime and nighttime incoming long wave radiation as well as back radiation.

#### b. Photographic exposure meters

Photographic exposure meters have been used with success in measuring incident light for photosynthesis studies by P. R. Nelson and W. T. Edmondson of the U. S. Fish and Wildlife Service. The

exposure meters used were calibrated against a pyrheliometer before use. Little is known of the accuracy possible with an instrument of this type, but, if sufficient accuracy is attainable, the use of exposure meters would afford a relatively inexpensive means of measuring radiation. It is recommended that the practicability of using exposure meters in heat budget studies be investigated and that some comparative experiments be conducted by the Hydrographic Office.

c. Other radiometers

It is known that several good radiometers have been developed in Europe which have not been evaluated by this Committee. It is recommended that investigations continue on the evaluation of existing foreign radiometers.

2. Instruments used below water

a. Open ocean clarity instrument

An instrument should be developed that is capable of measuring the attenuation of ambient light with depth as well as transparency in relatively clear open ocean water. It should be equipped so that a number of wave length ranges could be measured on one cast, thus shortening the amount of time necessary to complete a cast and minimizing the chance of changes in the illumination conditions.

b. Water clarity meter (photocell type)

The Visibility Laboratory recently proposed a radically new design for a second generation of water clarity instruments based on the principle of null balance. This design appears to promise improved reliability and operation for the water clarity meter, and it is recommended that development of the design and new instruments be followed closely by this Office.

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## IX. MARINE BIOLOGICAL SAMPLING

John R. DePalma

### A. INTRODUCTION

The complex problems of population dynamics demand a great variety of biological instruments for locating, observing, and collecting organisms varying in size, habitat, and motility. Emphasis on biological measurements is becoming more and more evident today in the consideration of the overall aspects of submarine and mine warfare.

On the basis of size, plankton have been classified into three kinds: (1) macroplankton, the large units of plankton, visible to the unaided eye, (2), net plankton, plankton secured by a plankton net equipped with No. 25 silk bolting cloth (mesh, 0.03 to 0.04 mm.), and (3) nannoplankton, very minute plankton not secured by a plankton net with No. 25 silk bolting cloth.

Plankton yield is a function of such aspects as distribution, productivity, and size, which in turn are influenced by wind action, currents, upwelling, predators, nutrient content of the water, diurnal migration, and physiochemical stratification. Plankton samples may include organisms that are contributing to fouling, light and sound scattering, and bioluminescence. Larger marine organisms may produce noises or otherwise interfere with underwater sound transmission. Fouling communities must be studied with particular reference to species distribution, growth rate, and ecological succession in order to predict accurately fouling conditions for any given area.

Plankton sampling instruments are evaluated according to how well they accomplish the following: collect from all depths, collect both horizontally and vertically, capture large and small specimens, capture the more active swimmers, secure undamaged specimens, record exactly the amount of water sampled and at what depth, sample over long distances, and sample several depths simultaneously.

### B. INSTRUMENTATION AND EQUIPMENT

#### 1. Meter (or half-meter) plankton sampler

A meter (or half-meter) plankton sampler consists essentially of three parts: a metal ring, one or one-half meter in diameter, provided with rope bridles for attaching to a tow line; a conical bag or net made

of silk bolting which acts as a sieve; and a metal collecting bucket at the cod end of the net.

This sampler is easy for one man to rig and operate and will capture a greater number of macroplankton than nets of smaller aperture. For qualitative work of a reconnaissance type, this net is rapid and effective. However, this net has a limited usefulness since no quantitative studies can be made without some modification, or the addition of a flow meter. It must be towed very slowly to eliminate backwash caused by small mesh size or clogging in the net. Deep tows and simultaneous collections are not considered practical with this sampler.

## 2. Clarke-Bumpus plankton sampler

The Clarke-Bumpus plankton sampler overcomes some of the serious limitations of the ordinary meter or half-meter samplers. The principle features are: a brass tube five inches in diameter and six inches long; a straining sleeve of silk bolting cloth attached to the tube by means of a ring with a bayonet-type lock, and a collecting bucket at the cod end; a propeller mounted in the tube, geared to a counter which registers the number of revolutions, and with calibration, the volume of water sampled; and two vanes, one on each side of the tube, which assist in holding the tube in a horizontal position. This apparatus may be opened or closed at desired depths by means of a messenger-actuated trigger.

The Clarke-Bumpus sampler has the obvious advantage of measuring the volume of water passing through the net. Clogging of the net and overspill or backwash caused by speeds between 5 and 10 knots are infrequent problems. Two or more of these samplers may be operated simultaneously at different depths on the same cable.

This sampler is limited to the collection of net plankton; macroplankton are able to avoid capture because of the small opening in the tube. It will not sample efficiently at high speeds (10 to 15 knots) or over long distances; nor will it withstand the added stresses of such speeds.

## 3. Hardy continuous plankton recorder

The Hardy continuous plankton recorder can be towed for long distances behind any ship at speeds to 15 knots. It is fitted with fixed planes which enable it to be towed at constant depths which are determined by the amount of towing cable payed out. Water enters a small hole in the front and passes through a tunnel and out the back. The plankton are sieved out by a continuously moving band of silk gauze

which is slowly wound across the tunnel and into a storage tank of formalin by a system of rollers geared to a propeller on the outside of the instrument. The propeller is turned as it moves through the water, and the gauze is moved in direct proportion to the distance the recorder travels through the water. Sections of the gauze are marked to correspond with previously determined distances, depending on the size or pitch of the propeller. For most collections, two inches of gauze for each mile sampled are recommended. The spools hold as much as 500 inches of gauze which allow nearly 250 miles of continuous data collection. As the gauze leaves the tunnel, it is at once joined by a second gauze strip which winds with it onto the storage spool in the formalin tank. This second strip prevents the plankton from being rubbed from one part of the roll to another.

This sampler has the advantage of being able to sample continuously for over two hundred miles and will indicate horizontal distribution or "patchiness" in plankton populations. It is possible to collect a very large amount of somewhat restricted data with this instrument with little effort or expense.

This instrument has an even smaller aperture than the Clarke-Bumpus sampler, and consequently most macroplankton will avoid capture. It is restricted to near-surface sampling and crushes some of the larger zooplankton.

#### 4. Issacs high-speed sampler

A high-speed sampler has been developed by the Scripps Institution of Oceanography that fulfills many of the requirements mentioned above. It is a streamlined tube containing a net and a depth registering flow meter. Water enters the sampler through a one-inch opening, is filtered by the net, passes around and activates the meter, and is ejected astern. The sampler has been constructed so that it precedes the cable by about a third of its length, thereby more readily capturing everything in its path. A depressor-vane is used to sample at depth.

This instrument is reputed to capture macroplankton, be useful at depths to 60 meters, perform well at high speeds (8 to 12 knots), give a record of both depth and flow, be useful over considerable distances, and be used in series alignment.

#### 5. Midwater trawl

The midwater trawl is used for collecting some of the larger and more active marine forms (nekton). The net of 2 1/2-inch stretch forms

essentially an asymmetrical cone with a pentagonal mouth opening and a round cod end. Additional netting of half-inch stretch is attached as a lining for the after end of the net. A steel ring is fastened in the cod end to maintain its tubular shape. A cup attached to the cod end retains the sample in a relatively undamaged condition. In front of the net a spread-V depressor-vane is rigged, and a spreader bar is attached to the leading edge of the top panel of the net. This device, however, is cumbersome to rig and difficult to stabilize in the water unless it is towed at a constant speed.

#### 6. Fouling plates

At the present time, fouling programs are largely restricted to quantitative studies of fouling plates. These plates are submerged to allow attachment of the fouling organisms and are analyzed on a monthly or seasonal schedule. Determination of species, growth rate, and growth pattern, as influenced by environmental conditions and time, are the aims of these programs. Supplementary visual and photographic observations are made of pilings, buoys, and other fouled objects in areas where no fouling plates are being studied.

#### 7. Noise level meters

These meters, although not specifically designed for this use, are being used successfully in studying sonic animals. Noises from these animals often are noted during underwater noise level measurements or seen as anomalous rises in the noise spectrum during frequency analyses.

#### 8. Echo sounders and rangers

These instruments also are not designed specifically for biological measurements. However, scattering layer studies are made by using them. It is assumed that most of the sound scattering is of biological origin, since the scattering layers perform daily vertical migrations in much the same manner as many planktonic animals nearer the surface.

#### 9. Nannoplankton samplers

Nannoplankton collections are difficult and time consuming to make. Their use in military oceanographic problems is extremely limited, and no descriptions of or recommendations concerning such samplers are included in this section.

## 10. Bioluminescence recorders

No instruments are in use by the Hydrographic Office at the present time for measuring bioluminescence. Displays are reported when observed in the field with a brief description of type (sheet, spark, or globe), intensity (can you read a newspaper by it?), and areal extent. It is understood that a project was begun at another agency to develop a continuous bioluminescence recorder that would consist of a tube with light baffles and a photoelectric cell to measure the bioluminescence produced by turbulence in the towed tube. However, this project has since been cancelled.

## C. CONCLUSIONS AND RECOMMENDATIONS

In quantitative plankton research, no instrument will obtain a fully representative sample of the organisms present in the water; most samplers are selective in one way or another. They may be selective as to size due to the loss of smaller organisms or the avoidance of the sampler by the larger and more agile ones. The selection may result from mechanical limitations of the gear or the methods employed in its operation. In addition, sampling reliability may be affected by the irregular distribution (patchiness) of the plankton.

The Clarke-Bumpus plankton sampler has received wide acceptance and is considered to perform well within its limitations. It is very useful when only small amounts of sample are required. The Hardy continuous plankton recorder and the Isaacs high-speed sampler also offer many attractive features.

The use of fouling plates for biological fouling studies is a widely accepted technique, and no recommendation for instrument purchase or development is made at this time.

The equipment currently available to the Hydrographic Office is considered to be adequate for reliable animal sound measurements.

Little information exists concerning bathypelagic organisms, and any detailed analysis of the Deep Scattering Layer will require sampling this group.

Accurate and reliable measurement of bioluminescent displays is impossible with present day methods. Development of a photoelectric luminescence recorder is currently feasible, if warranted.

The use of photometers or water clarity meters for certain types of plankton determinations has been suggested but undoubtedly will require further development.

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## X. BOTTOM MATERIAL AND STRATA DETERMINATIONS

Adrian F. Richards

### A. INTRODUCTION

A very good compilation of instruments used more than two decades ago to collect bottom sediments and rock is given by J. L. Hough (Reference X-9). More recently, R. S. Dietz published a brief summary of bottom sampling devices designed between 1940 and 1950 (Reference X-3). Operating instructions for a number of bottom samplers have been published by the Hydrographic Office (Reference X-34). In recent years instrumentation has been developed for obtaining continuous subbottom reflections of sediment strata. Appendix D of this report contains a comparative tabulation of known continuous-profile devices for which information is available.

### B. BOTTOM SAMPLING EQUIPMENT

Although sampling gear through the years has become increasingly numerous and varied, bottom samplers fall into three general categories: grab samplers, dredges, and corers.

#### 1. Grab samplers

Four types of grab samplers are in use by the Hydrographic Office: the Navy Electronics Laboratory-type clamshell snapper, a clamshell snapper of conventional design, the orange-peel sampler, and the underway bottom sampler or Scoopfish. These samplers are adequate to sample surficial sediments. If a large or somewhat less disturbed sample is required, the Van Veen grab sampler, as modified by the Woods Hole Oceanographic Institution in 1959, can be used. A large- and small-size Van Veen sampler, a Scoopfish, and an orange-peel sampler are considered adequate to handle all grab sampling requirements by the Hydrographic Office. (See References X-4, -14, and -34.)

#### 2. Dredges

Three types of dredges are used by the Hydrographic Office: (1) a light-weight, wire mesh, triangular dredge designed for collecting biological samples in shallow water, (2) a medium-weight, rigid, steel-sided, rectangular dredge designed for recovering loose rock, and (3) a heavy-weight, chain-link, rectangular dredge designed for breaking off rock in place and for all heavy dredging. These dredges

are considered adequate to handle requirements anticipated by this Office for such work. However, the larger dredges should be equipped with simple pipe dredges for the recovery of material smaller than the chain mesh and with fish-net liners. (See References X-22 and X-34.)

### 3. Corers

Coring equipment in use by oceanographers at the present time consists of three different basic designs: (1) the gravity-type, e.g. Phleger, corer, (2) the piston-type, e.g. Kullenberg and Ewing, corers and (3) the vacuum or hydrostatic-type corer, currently used only by the Soviets.

#### a. Gravity-type corer

This type of corer is inexpensive to construct and simple to operate. Cores over 16 feet long can be obtained with it under favorable conditions, although lengths of six or ten feet are the more usual maximum. The principal disadvantage of this type of corer is the low recovery ratio (core length to penetration of the sediment). Furthermore, no unanimity of opinion exists on how to correlate the length of the sediment core to the distance penetrated into the bottom. (See References X-5, -10, -11, -27, -30, and -37.)

The Phleger corer (Reference X-29) used by the Hydrographic Office, which obtains cores with maximum lengths of about three feet, is considered to be adequate for most reconnaissance needs. However, the diameter of the liner is too small to allow an adequate analysis of the engineering properties of the core. Also, the cutter area ratio,  $C_a$ \*, of 67.5 percent is somewhat large.

\*

$$C_a = \frac{D_w^2 - D_e^2}{D_e^2}$$

where

$C_a$  = cutter area ratio

$D_w$  = outside diameter of core cutter

$D_e$  = inside diameter of core cutter.

The Phleger corer used at the Scripps Institution of Oceanography has a cutter area ratio of 44 percent. As the cutter area ratio increases, the penetration resistance of the sampler, the possibility of increasing the recovery ratio to more than 100 percent, and the danger of sample disturbance also increase. It is considered advisable to decrease the outside diameter of the Hydrographic Office Phleger core cutter to reduce the cutter area ratio to a value between 30 percent and 40 percent and to replace the metal flapper-type check valve by a rubber stopper type which provides a better seal and usually allows the core catcher to be eliminated. The elimination of the core catcher is necessary for any engineering analyses of the sediment core.

Longer cores having a larger diameter than those from the Phleger corer can be obtained, if needed, by using a length of Kullenberg corer, or other larger diameter pipe, with an attached weight stand, check valve at the top, and a bail assembly.

b, Piston-type corer

The piston-type corer is the one most commonly used for coring bottom sediments. At the Hydrographic Office both the Kullenberg and Ewing piston-type corers are used. The Kullenberg corer has barrel lengths of six and 12 feet, a diameter of 1.875 inches (inside diameter of the core liner), and a core cutter area ratio of 94 percent; the sample is contained in a cellulose acetate liner. The Ewing core has barrel lengths of 20, 40, and 60 feet, an inside diameter of 2.5 inches, and a core cutter area ratio of 99 percent; the sample is contained in a metal pipe.

Several basic questions are connected with piston coring, all of which relate to the eventual use of the sediment core: (1) Does the sediment core represent *in situ* conditions? (2) are the core diameter and length adequate for the type of laboratory analysis required? and (3) can the sediment be removed from the core barrel or liner without introducing distortion or damage? (See References X-13 and X-32.)

Until recently, slight distortional effects were not considered deleterious to the eventual use of the core which more often than not was intended for geochronological studies. With the introduction of a Hydrographic Office testing program designed to determine the engineering properties of the sea floor, particularly as related to bearing capacity, distortional effects and disturbance to the core became a serious matter.

A new corer having a larger-diameter barrel of plastic was designed to overcome some of the problems encountered with corers previously used. This corer utilizes a barrel made of high-impact grade, polyvinyl chloride (PVC), extruded plastic without an inner liner. The barrel diameter is 3.50 inches outside and 3.22 inches inside. Barrels as much as ten feet long have been used successfully in water as deep as 1,200 fathoms. Piston and gravity cores eight and nine feet long, respectively, have been obtained. Tensile, compressional, and impact strengths of PVC are, respectively, about one-tenth, one-third, and one-half those of steel. PVC is light in weight (specific gravity of 1.35), easy to cut into short lengths, and cheap enough (about 75 cents per foot) to be expendable. This plastic appears to be nearly impervious to moisture and, consequently, requires no additional sealing except at the ends to insure interstitial water retention in the sediment core. The use of this corer, named the Hydro plastic-barrel corer, is recommended whenever engineering studies are to be performed on sediment samples. (See Reference X-31.)

#### c. Hydrostatic-type corer

The hydrostatic, or vacuum, corer was developed by Pettersson and Kullenberg and later modified by Sysoyev and Kudinov. The principal difficulty with this type of corer is that while sediment is sucked into the barrel at a relatively constant rate the corer penetrates the bottom at a decreasing rate; consequently, distortion of the sediment results from the discrepancy between the two rates. For this reason it is not considered advisable for the Hydrographic Office to acquire a hydrostatic corer, although it is capable of taking cores over 100 feet long under optimum conditions. (See References X-15, -28, and -38.)

### C. CONTINUOUS-PROFILE SUBBOTTOM EQUIPMENT SYSTEMS

Although thicknesses of bottom sediments were measured by echo sounding twenty years ago, continuous-profile devices for obtaining subbottom reflections are a relatively recent outgrowth of marine seismic reflection techniques. Echo sounders and continuous-profile equipment are similar and basically consist of: (1) a sound source transducer, (2) one or more receiving transducers, (3) a pre-amplifier, (4) a filter network, (5) a power amplifier, and (6) a recorder. Continuous-profile equipment systems are characterized by a sound source having a high repetition rate and filters to permit the selection of high frequencies (usually greater than four kilocycles) for the resolution of thin-bedded strata or low frequencies (usually lower than 500 c.p.s.) for maximum penetration of the sediments.

A number of different sound source transducer methods have been used: magnetostriction (Sonoprobe, Subsurex), ammonium dihydrogen phosphate (ADP) crystals ("Smith-Cummings-Meichner Apparatus"), electric spark (Subbottom Depth Recorder (SDR), Seismic Profiler), gas explosion (Subbottom Depth Recorder with repeatable acoustic sound source (RASS), Marine Seismic System), eddy current repulsion of a nonmagnetic disk (Sonar Thumper), and barium titanate (Stratagraph). The amplifiers and band-pass filters in all the systems are more or less conventional. Two types of recorders used with some of these systems are the Precision Depth Recorder (PDR) and the Precision Graphic Recorder (PGR). (These recorders are described in Section XI.)

At present, development of a transmitting transducer is devoted largely to obtaining a high-power, broad-band energy source having a high repetition rate. A short pulse length is required for thin-bed resolution: A one millisecond pulse will resolve strata about 2.5 feet thick. A very short pulse is possible with the Thumper, which is being modified to develop more power. The gas explosion sound source appears to promise maximum power, especially when the energy is directed downward by a wave guide such as used in the Marine Seismic System,

Progress in the development of continuous-profile equipment systems has been so rapid in recent years that it has been difficult to obtain enough facts to make valid comparisons between the different available systems. Information on known devices is listed in Appendix D, including specific references on each system. All of the instrument systems, except one were checked by one or more persons who either participated in developing the device or performed surveys with it. The one exception is the Marine Seismic System; information for this system was supplied by the manufacturer. A comparative tabulation that summarizes the various equipment also is given in Appendix D (Table D-1).

## D. CONCLUSIONS AND RECOMMENDATIONS

### 1. Bottom sampling equipment

Bottom sampling equipment for various survey or bottom analysis requirements are available and considered generally satisfactory for their intended purposes. Where grab samples are required, a large- and small-size Van Veen sampler, a scoopfish, and an orange-peel sampler are considered adequate to handle all anticipated requirements. The triangular, light-weight dredge and the two heavier rectangular

dredges are considered adequate for all dredging requirements by this Office. The Phleger gravity-type corer is satisfactory for most reconnaissance-type coring operations. When long cores are required, either the Kullenberg or Ewing piston-type corers can provide them. However, it is recommended that the recently developed Hydro plastic-barrel corer be used when less distorted, larger diameter cores are needed for engineering analyses. It is not recommended that the Hydrographic Office acquire a hydrostatic corer because of the distortion caused to the sediment core as it is being taken.

## 2. Continuous-profile subbottom equipment systems

The Sonoprobe appears to be satisfactory for all shallow water applications. The purchase of new equipment by the Hydrographic Office at the present time is not recommended until apparatus recently developed has been fully evaluated for suitability for the requirements of this Office. Within a year, investigations of different gas explosion sound sources and the Thumper may indicate the desirability of acquiring one of these systems for routine survey work in deep water. The Precision Graphic Recorder is considered to be more desirable than the Precision Depth Recorder for use with continuous-profile systems.

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## XI. BATHYMETRIC MEASUREMENTS

### Bathymetric Section Survey Branch

#### A. INTRODUCTION

The hydrographic survey programs of the Hydrographic Office include the measurement of depths of water in open ocean areas as well as in areas near the coast. The depths measured range from practically zero to about 6,000 fathoms. Although depths generally are expressed in fathoms, in shallow water it is customary to use feet and fractions of feet for greater definition. In many foreign countries other unit systems are used, the most common being the metric system. In coastal waters less than 100 fathoms, soundings are reduced for tidal height. The datum used for these reductions varies in different parts of the world. On the Atlantic coast of the United States, the datum is Mean Low Water, whereas on the Pacific Coast Mean Lower Low Water is used.

The echo sounding machine has almost completely replaced the older methods of obtaining soundings. This instrument consists of four parts: (1) A transmitter which generates an electrical impulse which is transmitted to (2) a transducer, which translates the electrical impulse into a sonic impulse at the same frequency either by means of the piezo-electric effect of quartz or other crystals or the magnetostriction effect of a nickel alloy embedded in a ceramic rod. The sonic impulse travels through the water to the bottom, or any other reflecting surface, and an echo is returned to the transducer where it is transformed again into an electrical impulse and passed to (3) a regular radio frequency receiver where the signal is detected, amplified, and sent to (4) a recorder where the travel time from the initial impulse to the return of the echo is measured and displayed. Most American-built instruments are calibrated for an assumed velocity of sound in sea water of 4,800 feet per second. The actual velocity varies with the temperature, pressure, and salinity of the water in the column being sounded. Since the actual velocity is normally faster than the calibration velocity, the sounding indicates slightly less water than actually is there, thus providing a safety factor. In effect, a repeatable depth rather than a true depth is indicated, since any ship using an echo sounder with the same calibration will obtain the same depth at a given location without the necessity of computation. For this reason, H. O. charts are published with soundings uncorrected for sound velocity.

It often is assumed that an echo sounding trace is a continuous and true profile of the ocean bottom, but it is not. First, the trace is a series of individual samples taken at short, but distinct, intervals depending on the repetition rate built into the transmitter. Secondly, the leading edge of the trace is the slant-distance to the nearest reflecting surface within the cone of sound emitted by the transducer. The shape of the trace will coincide with that of the bottom directly under the vessel only when the bottom is flat.

The directivity of a transducer is a function of the transducer diameter and the frequency of transmission used. As the diameter and the frequency are increased, the sound beam becomes more directional. However, narrow beams must be stabilized, so that they will not be affected by the motion of the ship. This stabilization presents a serious problem when a large transducer is used. Also, as the frequency is increased, the attenuation of the signal is greater and the available depth range becomes less.

## B. EXISTING INSTRUMENTS

The echo sounding equipment now available can be divided into three general classes of instruments: general purpose, shallow water, and deep water instruments.

### 1. General purpose instruments

These instruments are designed to give the navigator the necessary information for entering and leaving harbors. They usually record to an intermediate depth of approximately 200 fathoms, and many models are available from commercial sources.

### 2. Shallow water instruments

Shallow water instruments usually are portable and are normally used in the range of 0 to 50 fathoms. They are reasonably accurate, if the power source is constant. The Edo 255 is considered typical of this type.

### 3. Deep water instruments

These instruments have recorders that can be used for the full range of depths and are quite accurate if provided with a constant power source. They are hull-mounted and require that the ship be

drydocked for movement or adjustment of the transducer. The AN/UQN Sonar Sounding Set is considered typical of the deep water instruments.

Several different transducers have been used with the deep water instruments. The standard 12-inch transducer supplied with the AN/UQN uses a frequency of 12 kilocycles and has a beam width of approximately 60° and a depth range to 6,000 fathoms. An experimental, stabilized transducer, built by the David Taylor Model Basin, is 40 inches in diameter and has a cone width of 16° with a 12-kilcycle signal, or 6° with a 34-kilcycle signal. The second combination, however, provides a usable depth range of only about 1,000 fathoms, although depths as much as 2,000 fathoms have been recorded under exceptional conditions. General Electric has developed a new unit, the AN/SQN-6, which is a modification of the standard AN/UQN sonar set. This unit transmits on a frequency of 18 kilocycles and uses a newly designed 25-inch, stabilized transducer which gives a beam approximately 18° wide. The AN/SQN-6 has recorded depths of about 3,000 fathoms without difficulty.

For precision surveys in deep water, it has been found advantageous to use an expanded-scale recorder in place of the recorder supplied with the set. Two such recorders are now in use: the Precision Depth Recorder (PDR) and the Precision Graphic Recorder (PGR).

#### a. Precision Depth Recorder (PDR)

This recorder is built by the Times Facsimile Corporation as a modification of the Times Facsimile radio receiver. The PDR uses an electro-sensitive paper, has a paper speed of 24 inches per hour, and displays 400 fathoms over a width of 18.85 inches. It phases automatically so that depths to the full range capability of the sonar set can be recorded in increments of 400 fathoms with high precision. The PDR triggers the sonar set and performs the time measuring function to about one part in a million. However, the equipment has a 400-fathom phase ambiguity, because no positive indication is given as to which multiple of 400 fathoms is being displayed on the record. In addition, the fact that the sonar set was not designed to operate with this recorder leads to overloading of the sonar set when sounding work is carried on continuously over long periods of time.

#### b. Precision Graphic Recorder (PGR)

This instrument, built by the Alden Electronic and Impulse Recording Co. for the Woods Hole Oceanographic Institution, is similar to the PDR, but it is considered to be more versatile in that

it has many scale and depth combinations readily available. However, the PGR is also rather more complex than the PDR. It uses a helix instead of the stylus of the PDR for recording. Although this is felt to be an improvement, the helix requires a wet-chemical paper, which is regarded by some as objectionable. The PGR requires further evaluation, in that it, too, is not entirely compatible with the sonar sounding set.

## C. CONCLUSIONS AND RECOMMENDATIONS

### 1. Shallow water instruments

The existing equipment for shallow survey work is considered to be sufficiently accurate, but it is difficult to maintain and does not perform consistently to depth specifications. The Hydrographic Office is closely following the current efforts of the Coast and Geodetic Survey to have an improved portable echo sounder developed by a commercial firm.

### 2. Deep water instruments

The present precision deep water sounding equipment has been developed piecemeal. It is recommended that this equipment be redesigned into a single piece of equipment that would embody the best features of the AN/UQN, PDR, and PGR.

The present equipment, particularly as to transducer directivity, is a compromise. It is recommended that a study be made of the latest advances in sonar design with a view toward increasing the directivity of the sound beam without sacrificing depth range or stability. It has been suggested, as a possibility, that a transducer of considerable size could be developed of multiple facets, each independently stabilized.

The precision deep water echo sounder should be capable of sounding to maximum ocean depths of 6,000 fathoms with a beam width sufficiently narrow to provide resolution of bottom features. Such resolution, which varies with the nature of the bottom and with horizontal position uncertainty, may require beam widths as narrow as 6°, or even 1° in special cases.

### 3. New instruments

A new system is required to combine depth information with automatic position plotting equipment, preferably plotting depth contours within the range of unrefracted sound rays.

The feasibility of an airborne sounding system should be determined. If such a system is feasible, it should be developed and combined with a suitable navigation system for the rapid surveying of large areas.

The Hydrographic Office intends to monitor any new instruments developed to ensure that they include features which would facilitate the processing of the results obtained and to test these instruments when developed to determine their accuracy and reliability under survey conditions. RDT&E funds for FY 1962 are being requested to support specific work.



## XII. TIDE MEASUREMENTS

### Hydrography Section Survey Branch

#### A. INTRODUCTION

The tide measuring program of the Hydrographic Office is directed primarily toward obtaining tidal data for the reduction to a datum plane of soundings taken at different stages of the tide and for correcting levelling nets established in remote areas where a vertical datum has not previously been established. These data are of interest to the scientist, the general engineer, the mariner, and the public in general. Tidal data are necessary for: the determination of the origins of elevation essential to general engineering; the utilization of ports and the construction of port facilities; and the prediction of tides, crustal movements, and coastline changes.

Measurements of tidal ranges are expressed in either feet or meters. Accuracies of  $\pm 0.05$  foot are practicable. Tides in general are caused by the gravitational attractions of the moon and the sun; however, variations in tidal range are complicated by the interference of irregularly distributed land masses with water movement, meteorological conditions, and the relative positions of the sun and the moon with respect to the earth. The actual effect of land mass distribution is not readily apparent at any location. Although the lunar-solar effect is predictable through a knowledge of the phase cycle, tidal measurements must be made to determine the parallax cycle and the declination cycle.

Tide measuring stations are classified as primary or secondary stations. Primary stations are somewhat elaborate and generally are established to obtain data over long periods of time. Secondary stations are established for specific purposes and are removed after the requirement has been met. Errors in the datum, inherent in the incomplete cycle of the secondary station, generally can be reduced by comparison of the secondary station data with data obtained from the nearest primary stations.

Tide measurements generally are accomplished either by using automatically registering tide gauges or nonregistering tide gauges. A precise echo sounder on board an anchored ship also can be used when conditions are satisfactory. The automatically registering tide gauges generally consist of a float or pressure gauge, a staff, and some type of clock-driven recording device, suitably housed, which

registers the rise and fall of the tide in the form of a graph. This type of gauge is unattended except when it is necessary to correlate the staff with the graph, reset the clock to the proper local time, and change the paper roll. The nonregistering gauge is, in general, some sort of pressure gauge, float, or staff, from which an attendant records data periodically.

## B. EXISTING INSTRUMENTS

### 1. Portable automatic tide gauge

This instrument is in general use by this Office. The gauge was designed especially for use at tide stations which are to be in operation for only short periods of time. Ease of installation of such instruments is a prerequisite. The float well is easy to install, and the pipe to the float well serves as the support for the recording device. The recording device consists of an eight-day clock that drives a recorder drum. A spring-loaded recording stylus is operated by the float. No elaborate housing is required for the recording mechanism. The gear ratios of the recording stylus are variable to accommodate a wide range of tides. The accuracy of this gauge is about  $\pm 0.1$  foot, and the price is approximately \$660.

### 2. Foxboro tide gauge

Recent developments in the pressure-type gauges have greatly increased the efficiency and accuracy of this type of gauge. Currently none are in use by this Office, but they have been used with some success by other agencies. One type, the Foxboro tide gauge, claims an accuracy of  $\pm 1/4$  foot and is priced at about \$200. This instrument is operated by the change of pressure caused by the change in water level above a pressure plate. The pressure change is converted to a pen deflection in a recorder, and the change in the level of the tide appears as a graph. The advantages of this gauge are its ease of installation and its capacity for transmitting measurements to one or more receivers as far as 500 feet from the sensing element. It can be used at any place where sufficient water is present to cover the element. No permanent installation of any type is required. It would appear that this type of instrument would prove useful in areas that do not readily permit the use of the standard automatic portable tide gage and/or in instances where data are to be collected for brief periods of time. It is also possible that the recording method may facilitate the data handling.

## C. CONCLUSIONS AND RECOMMENDATIONS

The portable tide gauges currently in use by this Office are satisfactory and fulfill most of the present needs. However, it is intended that instruments of the Foxboro type be tested and, if satisfactory, adopted for survey use. Additionally, the possibility of transmitting measurements from one or more tide gauges to a central collection point several miles away will be investigated as part of the RDT&E effort in FY 1962.



### XIII. GRAVITY MEASUREMENTS

#### Geophysics Section Survey Branch

##### A. INTRODUCTION

The gravity program of the U. S. Navy Hydrographic Office includes measurements of the vertical component of the earth's gravitational field on land and sea and probably will include measurements in the air within the near future. These data are required for correcting astronomically determined positions on the earth for observational error due to deflection of the vertical, an effect created by the unequal distribution of mass in the earth's crust. These data also are required for use as an aid to navigation by submerged submarines and for calculating area deflections of the vertical for missile guidance systems.

Measurements of gravity are expressed in gals (for Galileo) and milligals, one gal being equal to an acceleration of one centimeter per second per second. Accuracies in the order of one part per million are readily obtainable. Variations in gravity are caused primarily by topography, since variation is a function of the distance from the center of the earth. Other factors contributing to variations in gravity are the shape of the earth and the geologic structure of the earth's crust. Values of gravity on the earth's surface range approximately between 978.0490 gals at the equator to 983.2213 gals at the poles ( $\pm 5,200$  milligals). A one-foot change in elevation is equivalent to a 0.094-milligal change in gravity on land or a 0.068-milligal change under water. For geodetic and navigation applications, measurements in the order of 0.1 milligal are considered to be sufficiently accurate.

Measurements of gravity are accomplished generally by one of three methods: dropped ball, pendulum, or spring gravimeter. Only the last is used by the Hydrographic Office. Absolute measurements of gravity are complicated and required at only a few places in the world to establish a primary reference for all other measurements. The absolute measurement is accomplished by accurately timing the acceleration of a mass (ball, cylinder, etc.) falling over a known distance in an evacuated chamber. The National Bureau of Standards currently is engaged in constructing the necessary equipment for a new and more precise determination of absolute gravity by this method.

Fortunately geodesy generally is concerned only with measuring the difference in gravity from one place to another, and such measurements are fairly simple to make. Relative gravity measurements are

accomplished in two ways: with a group of pendulums, by determining the variations in the periods of swinging pendulums of known lengths at different locations; or by means of a spring-type gravimeter, by measuring the variations in the length of a weighted spring at different locations.

## B. EXISTING INSTRUMENTS

The status of instruments pertaining to gravity surveys may be considered good insofar as the needs of the Hydrographic Office are concerned. The several types of instruments available or currently under development are discussed below.

### 1. Airborne gravity instruments

Some laboratory research and a few field trials have been carried out toward the development of an airborne gravimeter. Lundberg Explorations, Ltd. of Toronto, Canada and Pick Laboratories of Saratoga, California have experimented with gradiometer-type instruments. These instruments involve systems that use two masses suspended vertically, one above the other, to permit observation of a ratio or a derivative of the vertical gradient of gravity. This principle appears to be applicable to exploration surveying, but it complicates the data processing for geodetic use. Neither of these companies has produced a working instrument to date.

Several tests have been made with existing gravimeters in a balloon and aircraft. The Air Force Cambridge Research Center (AFCRC) made the first feasibility test using a LaCoste and Romberg shipboard meter aboard a KC135 (jet tanker) at Edwards AFB, California in November 1958. Flights made at 20,000 and 30,000 feet proved that such an instrument would operate under these conditions. Three Companies: LaCoste and Romberg, Fairchild Aerial Surveys, and Gravity Meter Exploration Co., known as FLAGs, then conducted a similar test aboard a B-17 aircraft flying at 12,000 feet. Since the completion of these initial tests, AFCRC has been continuing research and development to determine the correlation between airborne results and ground data, to improve methods for reading the meter at high speeds, and to provide means for rapid calculation of data. FLAGs currently is planning a test aboard a helicopter which, if successful, should contribute greatly to the solution of the problem of correlating air and surface data.

### 2. Shallow water gravimeters

Shallow water gravimeters are required on surveys made to

fill the gaps between ship operations and land-based surveys and in areas such as lagoons or inland lakes. Several commercially produced gravimeters for shallow water work currently provide the accuracy and stability necessary for all foreseeable requirements. Their prices range from \$30,000 to \$35,000. These instruments are operated by remote control from surface ships to depths as much as 200 fathoms and have an attainable accuracy of 0.1 milligal.

These meters, in general, weigh approximately 250 to 350 pounds and require the use of two cables with their corresponding winches during operations. One cable is used only for lowering and raising the meter, and the other is a waterproof multiconductor cable which can support only its own weight at 200 fathoms.

Recent developments in this type of meter have produced a much smaller meter that weighs only about 90 pounds. This meter is self leveling, a feature which greatly simplifies the observing procedure and reduces the size of the required multiconductor. As a result, it has been possible to develop a single-cable system in which the conductor cable also supports the meter.

### 3. Submarine and surface ship gravimeters

Although ocean gravity meters were designed initially only for submarine use, recent improvements have made the meters operable on surface ships. It is, therefore, preferable to designate these instruments as ocean meters for use aboard either submarines or surface ships. The Hydrographic Office owns two LaCoste and Romberg meters and has technical control of three others. In addition, this Office has been evaluating three Askania (Graf) gravimeters constructed in West Germany. Several other commercial organizations currently are developing meters for use at sea. The LaCoste and Romberg meter costs about \$150,000 and includes a computing system and a means of keeping itself level. This meter is electrically operated and has an attainable accuracy of 0.1 milligal with precise navigation in average sea conditions. The Graf meter costs about \$27,000 but requires a stabilized platform for operation.

### 4. Absolute gravity instruments (land)

Gravity instruments for use on land are of two categories, absolute and relative-reading. Although most of the requirements for gravity surveys can be accomplished with relative-reading instruments, absolute measurements of gravity are required for basic control of all surveys. No truly absolute gravity instrument is available

at present, and such measurements are confined to laboratory practice; however, development of a portable apparatus that shows great promise is underway. In lieu of such an instrument, the pendulum apparatus is considered to be sufficiently stable for establishing base control stations. Current programs include the establishment of secondary pendulum stations that will be related to the few primary national bases and supplemented by gravimeter readings made for the detailed surveys relative to the secondary pendulum bases. This has not been a satisfactory plan in the past, since old pendulums were inaccurate, bulky, affected by other natural phenomena, and not usable as portable instruments. New pendulum instruments more nearly satisfy the needs, but they still are not as precise as gravimeters. However, gravimeters, have problems of drift. Therefore, a portable, absolute (no drift) measuring device should be developed to provide a means of establishing secondary control points accurate to 0.1 milligal.

## 5. Geodetic gravimeters

Currently available at the Hydrographic Office are five commercially produced land gravimeters: two Worden, one North American, and two LaCoste and Romberg. All of these instruments have attainable accuracies of 0.1 milligal and meet the requirements of this Office with respect to land gravity surveys. Each of the meters incorporates certain desirable features, but each also has some disadvantages for world-wide surveys.

### a. Worden gravimeter

This instrument is light-weight, compact, and very good for local surveys, or for establishing connections between points that are reasonably close together. The meter is temperature compensated (not controlled) and is easily read, except that it must be lifted off its tripod for reading the dials. The meter is calibrated in the factory by a tilt-table method which is not as precise as are observations on the ground over a known range of gravity. The calibration curves are generally convex, but, as with all gravimeters, they can be changed by rough handling of the instrument. Disadvantages of the Worden gravimeter include the problem of drift (a slow but continuous change in readings due to the relaxation of the spring system) and the lack of a method to clamp the measuring element when it is not in use. The two meters owned by this Office also are limited in their range of use: one is set for use from the equator to approximately 45° north and south latitude, and the other for use between about 30° and 90° north and south latitude. Because of the inherent drift in these meters, they usually run out of the reading range within four years and require

resetting in the factory. The Worden meters were purchased by the Hydrographic Office in 1950.

Recent improvements in the Worden gravimeter have upgraded the quantity and quality of observations obtainable. The new Master model includes low-power temperature stabilization, positive linear drift, a gearless top-reading dial, and a world-wide range. The present price of the new meter is about \$8,500.

b. North American gravimeter

This meter is temperature controlled, thus eliminating drift, and has a total range of 1,000 milligals. However, it can be used world-wide by resetting it. The measuring element can be clamped when not in use. Calibration by the manufacturer gives a constant value over full range which appears to be good from field checks made by this Office.

The principle drawbacks of this meter are its size and weight and the extreme sensitivity of the reading mechanism. Two people are required to transport the meter in the field; it is time-consuming to operate and requires frequent battery changes to maintain constant temperature. This meter has not proven satisfactory for general use by this Office, but it was the only instrument of its type available when it was purchased in 1952. The price of this meter is about \$8,500.

c. LaCoste and Romberg gravimeter

Two meters of this manufacture have been purchased by the Hydrographic Office. The first meter, an early model, was purchased in 1957 for \$10,000. It is a temperature-controlled instrument with a world-wide range usable without resetting. The calibration by the manufacturer was made on a range at Cloudcroft, New Mexico and is a straight line over the entire reading range. The meter is easily read by means of a counter dial and has the most stable reading indicator of all meters on hand. Very little drift occurs, and reading continuity is not lost with loss of heat. The chief disadvantages of this meter are its size and weight and the size and weight of the power supply required for temperature control. These limit the utility of this meter in that it is difficult to handle in the field unless the terrain permits the use of a vehicle.

The second meter was purchased in 1960 for \$10,000. This meter is a miniaturized version of the previously described meter, and it

maintains all the desirable features and eliminates most of the disadvantages. The size has been reduced so that the meter, rechargeable power supply (batteries), and battery charger and battery eliminator weigh a total of about 15 pounds. The combination of no drift, rapid reading, and facility of transportation makes this a good instrument for world-wide operations.

d. Other gravimeters (land)

In addition to the types of gravimeters currently owned by the Hydrographic Office, one other manufactured in the United States, the "World-Wide" meter, is described as being very similar in most respects to the Worden meter. Several foreign-made gravimeters also are currently on the market, but from all reports these are less accurate than the U. S. instruments.

## C. RECOMMENDATIONS

### 1. Recommendations for improvement of existing instruments

a. Although currently available gravimeters meet most survey requirements, submarine meters should be converted for either shipboard or submarine use and miniaturized to permit operation in all sea conditions. The small size also would permit continued use aboard submarines when required. As practicable, ocean gravity meters should be included as standard items aboard all Hydrographic Office survey ships.

b. A calibration range for use in checking and calibrating all sea gravimeters should be established at sea along the east coast of the United States. The range should consist of several accurately surveyed areas each approximately one degree square, and located at intervals of  $5^{\circ}$  of latitude. Meanwhile, calibration of all gravity instruments in this Office should be accomplished as soon as practicable over all or part of the coastal areas presently surveyed in the region extending from Ottawa, Canada to Key West, Florida. This is necessary for accurate comparison of all data obtained with various meters and should be done at regular intervals to insure that any changes of calibration are known.

c. Navigational instruments should be improved or developed to allow more accurate positioning than can be achieved at present.

## 2. Recommendations for development of new instruments and methods

a. A small, portable instrument should be developed for measuring absolute gravity with a probable error not to exceed 0.1 milligal.

b. Development of a miniaturized, automatic gravimeter for operational use by submarines should be initiated. This meter should be as nearly automatic as possible with provisions for feeding the raw data directly to a computer. The meter should be sufficiently simple to be operable by one semiskilled person and should require a minimum of maintenance.

c. In view of the aircraft presently in use by the Hydrographic Office for Project MAGNET, development of an airborne gravity meter, which could be utilized in conjunction with magnetic surveys, should be encouraged and monitored by this Office.

d. Each new gravity instrument developed for geodetic operations should have world-wide range to avoid resetting problems and have a calibration correction over its full range as nearly linear as practicable (and, if possible, a constant).

e. New methods of recording and processing gravity data from ocean surveys should be investigated, and a system compatible with data processing methods adopted for general use by the Hydrographic Office should be developed.

f. It is recommended that a continuing liaison be maintained by this Office with commercial laboratories and other government activities engaged in development of new gravity instruments. In view of the responsibility of this Office for ocean gravity surveys, final Navy acceptance of all instruments for this use should be subject to approval after evaluation by the Hydrographic Office. Comparative tests of all new instruments should be accomplished as rapidly as practicable and witnessed by representatives of the manufacturers concerned, the Hydrographic Office, and an impartial activity such as the Coast and Geodetic Survey.



## XIV. GEOMAGNETIC MEASUREMENTS

Floyd Woodcock and A. Joseph Heckelman  
Geomagnetics Branch

### A. INTRODUCTION

World charts of all elements of the earth's magnetic field are published by the Hydrographic Office. These charts are brought to epoch by the application to old data of known or estimated secular change rates and by the inclusion of new data. Magnetic data compiled from foreign agencies and various U. S. agencies, including the Hydrographic Office, are maintained in a central U. S. depository. At present, airborne geomagnetic surveys by the Hydrographic Office are virtually the only available source of new data for the ocean areas of the world.

Magnetic Variation (Variation of the Compass) Charts are published each five years, for Epochs 1955, 1960, 1965, etc. Horizontal Intensity, Vertical Intensity, Magnetic Inclination (Dip), and Total Intensity Charts are published each decade, for Epochs 1955, 1965, 1975, etc. Charts published subsequent to Epoch 1955 reflect the new data obtained by Hydrographic Office surveys over the ocean areas.

Magnetic information is important to a variety of military applications, some of which are: (1) USW, ASW, and mine warfare, (2) weapons systems, (3) guidance, (4) navigation, direction and position fixing, (5) degaussing, and (6) compass swinging. All nautical and aeronautical charts include magnetic declination information needed by navigators.

The Hydrographic Office receives frequent requests for magnetic data from persons and agencies engaged in geophysical research. Studies of interactions between the geomagnetic field and charged particle motions in the upper atmosphere and space are advanced by a thorough knowledge of terrestrial magnetism.

In many cases, limitations on the applications of geomagnetism are imposed by nature itself. Irregular temporal changes and anomalies in some cases are limitations. In addition, inadequate knowledge of geomagnetism often imposes still stricter limitations. The latter, however, can be looked upon as a challenge.

### B. DEFINITIONS OF TERMS

Some of the terms used in geomagnetic measurements are defined

below to eliminate any chance of confusion as to their usage and to provide an additional background to this discussion.

### 1. Magnetic field

A magnetic field is a region within which a magnet can experience a torque. The earth surrounds, and is surrounded by, a magnetic field which is a vector field. The complete measurement of the earth's field at any place consists of determining both the direction and magnitude of that field.

### 2. Magnetic intensity

The scalar magnitude of a field vector is called intensity. Total intensity denotes the scalar value of the magnetic field vector.

### 3. Magnetic elements

The magnetic field vector commonly is defined by various coordinate systems. These are:

a. Horizontal intensity (H), Vertical intensity (Z), Declination (D)

b. North horizontal intensity (X), East horizontal intensity (Y), Downward vertical intensity (Z)

c. Total intensity (F), Inclination (I), Declination (D)

d. Horizontal intensity (H), Inclination (I), Declination (D)

Transformations from one system to another, or to any orthogonal system, readily can be made. Sometimes other systems are used, particularly when only field variations are of interest.

### 4. Common units of measure

The c.g.s. unit of magnetic field intensity is the oersted which is equivalent to a force of one dyne per unit north magnetic pole. In geomagnetism where the field is small, the gamma ( $\gamma$ ) is used as a unit of intensity. One hundred thousand gammas equal one oersted. Directions are commonly expressed in degrees of arc.

### 5. Gradient

The c.g.s. unit for a spatial gradient is oersteds per centimeter,

and for a temporal change oersteds per second. However, it is normal to use more convenient units such as gammas per foot, gammas per meter, gammas per mile, etc., for spatial gradients, and gammas per second, gammas per minute, gammas per hour, etc., for temporal change rates.

## 6. Anomaly

A spatial disturbance in the geomagnetic field, where the intensity of the field departs significantly from the surrounding values, is an anomaly. The significance of such departures is determined by the intended application of the data. Anomalies are accompanied by gradients and other higher derivatives of the field, and their causes are natural or man-made.

## 7. Daily variation

Solar-daily variations in the magnetic elements are daily periodic variations. The daily range, which varies with the latitude, time of year, and sunspot cycle, is not entirely consistent, however, and can vary widely at a given place, regardless of the time of year, etc. Lunar-daily variations also occur and are periodic over lunar days. These latter variations are minor.

## 8. Annual variation

Small variations periodic over a year are annual variations. Their magnitude is less significant than the solar-daily variations.

## 9. Annual change

The year-to-year change rates in the magnetic elements are annual changes. These changes are associated with Secular Variations which are impressively slow variations and which are probably periodic. Secular Variations apparently require centuries for their full development.

## 10. Irregular disturbances

At irregular intervals disturbances occur which can, from time to time, attain considerable magnitude. The larger disturbances are called Magnetic Storms and may last several hours or several days. They may cause a change of several degrees in declination and of several percent in horizontal intensity and occur almost simultaneously over the whole world.

## 11. Artificial disturbances

Man-made disturbances are generated by accumulations of ferromagnetic materials such as structures, ships, submarines, mines, etc. In general, these artificial anomalies are considerably smaller than naturally occurring anomalies. Artificial disturbances also can be caused by electric currents.

## C. AIRBORNE GEOMAGNETIC SURVEYS

Since 1952 the Hydrographic Office has been conducting airborne geomagnetic surveys using an NOL Vector Airborne Magnetometer, Type 2A (VAM-2A). This instrument was developed and two prototypes constructed by NOL under joint sponsorship of this Office and Office of Naval Research. After a period of testing and evaluation, two additional instruments, designated VAM-2B, were procured by the Hydrographic Office under commercial contract.

Currently one VAM-2A is installed in an R5D aircraft and one VAM-2B in a WV-2 aircraft. Both aircraft have been modified extensively to facilitate accurate airborne measurements of the geomagnetic field. Both aircraft are provided with a variety of special navigational equipment. The WV-2 aircraft is provided with a Kollsman KS-124 photoelectric sextant to supplement the VAM system. A cosmic ray neutron monitor also is installed in the WV-2.

### 1. Vector Airborne Magnetometer

The VAM system is one whereby four parameters are measured directly: (1) Magnetic heading (MH), (2) inclination (I), (3) celestial relative bearing (RB), and (4) total magnetic intensity (F). The VAM utilizes three mutually perpendicular saturable inductors, two for orienting the servomotor control and the third for measuring the total field. A modified Kollsman periscopic sextant, manually operated, is used to measure celestial relative bearing (RB).

The VAM measurement of total field intensity (F) is accomplished by passing a precisely controlled electric current through the detector inductor which is servo-oriented parallel to the magnetic field vector. This "neutralizing" current is manually adjusted in precise 50-gamma steps ( $1 \text{ gamma} = 10^{-5} \text{ oersteds}$ ) to establish base lines. The detector inductor a.c. output voltage is an amplitude analog of the difference between the ambient field and a base line value. This analog value is detected and recorded on an Esterline-Angus recorder to an accuracy of about  $\pm 3$ ,  $\pm 9$ , or  $\pm 15$  gammas depending upon the sensitivity selected.

The base line values, which are manually tabulated, are established to an accuracy of about  $\pm 20$  gammas. The base line accuracy is largely dependent upon the stability of a group of mercury cells and standard cells used as a voltage reference.

The VAM utilizes a synchro system wherein a synchro control transmitter is geared to the inductor-orienting device (or sextant mount, in the case of RB). The transmitter is connected to a remote synchro control transformer which is manually indexed to integer  $5^\circ$  base values (within  $5^\circ$  of the unknown angle). The transformer a.c. output voltage, an amplitude analog of the difference between the unknown and base values, is detected and recorded on two Esterline-Angus recorders to give both a direct (instantaneous) value and a value integrated over 100-second time intervals. The overall accuracy exclusive of navigational and vertical reference errors is about  $\pm 0.12$  degree or better for each angle.

The VAM vertical reference is provided by suspending the detecting mechanism as a viscous-damped pendulum gimballed about the pitch and roll axes of the aircraft. The gimbal mechanism and detector are supported on a shock-mounted base. Ideally, in level flight the average acceleration acting on the pendulum is the combination of gravity and the Coriolis force. The deflection caused by the Coriolis force is compensated by a manual adjustment. The angular data are integrated for 100 seconds to achieve values with respect to a reasonably good average vertical reference. However, this reference is affected by aircraft accelerations and turbulence.

## 2. Nuclear Precession Magnetometer

The Varian V-4910 magnetometer measures total magnetic intensity only. The instrument is absolute and nearly drift-free. The principle of operation is based upon the gyromagnetic characteristics of protons which can be made to precess like tiny spinning tops at a frequency proportional to the magnetic field. However, the V-4910 has not yet been installed for airborne survey use.

The data, digital rather than analog, will be punched periodically on a paper tape as a twelve-digit binary number. The output also is converted to an analog form and displayed on a Sanborn recorder.

It is expected that the detector will be towed in an aerodynamic "bird" developed by the Naval Air Development Center, Johnsville, Pennsylvania, or possibly in a "drogue-like" device.

### 3. KS-124 Photoelectric Sextant

An AN/AVN-1 astro-navigational set has been modified by the manufacturer to specifications provided by the Hydrographic Office to measure precise, averaged, celestial relative bearings. This automatic star-tracking device has been coupled with the VAM program timers to provide synchronized data. KS-124 data are presented on mechanical counters and recorded automatically by a synchronized data camera.

The KS-124 ultimately should replace the manually operated VAM perisopic sextant, resulting in increased accuracy and permitting the observer to assist in monitoring the magnetometer and navigational equipment. However, the necessary reliability and accuracy have not yet been demonstrated for this instrument.

### 4. Accuracy of airborne magnetic surveys

Under good flight conditions, the VAM system is believed to be sufficiently accurate for present and proposed future requirements of the world charting program. The accuracy of the survey depends upon: (1) Magnetometer accuracy, (2) aircraft compensation accuracy, (3) navigational accuracy, (4) presence of magnetic anomalies, and (5) size of magnetic temporal variations.

#### a. Magnetometer accuracy

To a large extent the measurements to define the direction of the magnetic vector are weather dependent. Turbulence and acceleration cause vertical reference errors which, in turn, can lead to substantial errors in the computed results. Gross errors, however, should be readily apparent in a sequence of closely spaced readings along a track line. Cloud cover prevents measurement of the relative bearing (RB), and thus of declination (D).

#### b. Aircraft compensation accuracy

Horizontal components of the permanent and induced fields of the aircraft are compensated until the deviations in measured  $F$  with respect to the aircraft's MH, for cardinal headings, is about 5 gammas or less. When this is done at a site where the inclination,  $I$ , is about  $60^\circ$ , the residual horizontal field of the aircraft should not exceed about 10 gammas. The vertical component of the aircraft's own field is somewhat more difficult to identify. The residual vertical field of the aircraft, after compensation, is probably not more than 10 gammas for a limited

range of I. For a world-wide range of I, the residual vertical field of the aircraft may be somewhat larger.

c. Navigational accuracy

Under ideal conditions it is probable that the aircraft position is determined to about  $\pm 5$  miles when far at sea. Adverse weather conditions can degrade this accuracy severely.

d. Magnetic anomalies

The presence of magnetic anomalies can often be deduced from the VAM magnetic profiles, but the effect on survey accuracy may remain uncertain.

e. Temporal variations

Time variations in the geomagnetic field sometimes can be deduced from magnetic observatory records, but the effect on surveys is uncertain.

## D. MARINE GEOMAGNETIC SURVEYS

The Hydrographic Office currently is conducting extensive marine magnetic surveys. The magnetometers used in these surveys are designated XN-4901 and are modifications for marine use of Varian V-4910 airborne nuclear precession instruments. The XN-4901's are installed aboard three survey vessels.

The Varian XN-4901 Marine Navigational Aid Magnetometer is a nuclear precession instrument. The sensing head, with its liquid hydrocarbon sample is towed sufficiently aft of the ship to remove it from the magnetic field of the vessel. The instrument measures absolute magnetic total intensity and is drift-free. The principle of operation is based upon the gyromagnetic characteristics of protons, which will precess like tiny spinning tops when in an ambient magnetic field at a frequency proportional to the total intensity value of that magnetic field. Equipment sensitivity is limited for practical purposes to the inherent accuracy of the counting circuitry.

The counter uncertainty is in the order of  $\pm 1$  to 2 gammas. The instrument field range is 25,000 gammas to 73,000 gammas, with the range being selected by 15 plug-in units. The ultimate sensitivity of nuclear precession magnetometers that use the most refined components and techniques under ideal static conditions appears to be about 0.1 gamma.

The field is sampled at two- or four-second intervals at the discretion of the operator. The time necessary for each field reading varies but is in the order of 1.4 seconds.

The XN-4901 is designed for both analog and digital data output. The analog output, as is currently used, appears on a Varian G11 or G11A strip chart recorder.

## E. LAND MEASUREMENTS

As a part of regular hydrographic surveys, Hydrographic Office personnel also occupy land magnetic stations in the course of establishing a base triangulation net. Instruments currently available for this purpose are Ruska field magnetometers. These instruments are quite satisfactory for the establishment of repeat magnetic stations. The observations, however, are quite time-consuming.

## F. SPECIAL PURPOSE SURVEYS

Surveys to determine the magnetic environment of an area are required for various applications. Factors required are: (1) Spatial distribution of magnetic anomalies, (2) characteristics of magnetic temporal variations, and (3) propagation geometry of induced magnetic fields. The Hydrographic Office currently is engaged in surveys which fulfill a portion of these requirements.

## G. CONCLUSIONS

### 1. Airborne geomagnetic surveys

In general, the instrumentation for airborne geomagnetic surveys can be considered reliable and accurate. Present capabilities for navigation and flight control impose limitations on the realizable accuracy of the survey. Improvements to the magnetometer equipment alone cannot be expected to yield substantially increased accuracy. However, certain aspects of the present systems can and should be improved in order to achieve greater flexibility, economy of effort, and reliability.

### 2. Marine geomagnetic surveys

The present marine geomagnetic survey equipment is standing up well under steady operations. The weak points in the system have been in the towing gear, both in the fish and the cable. However, recent advances show good promise of alleviating these difficulties.

The development of small, simple, easily towed total magnetic field sensors which are virtually insensitive to motion, temperature, pressure, etc. has made possible the routine acquisition of magnetic data from ships.

The sensitivity of the nuclear precession magnetometer is generally adequate for measurement of the total intensity value of the magnetic field, but is not sufficient to allow use of the instrument as a high resolution magnetic field gradiometer. A more recent development, the rubidium vapor magnetometer, offers a higher order of sensitivity (in the order of 0.01 gamma). This instrument appears to possess all of the important advantages of the nuclear precession instrument together with a sufficiently high accuracy to make it suitable for gradiometer use.

### 3. Land measurements

In order to facilitate repeat station observations and reduce the time required to occupy a station, it would be useful to employ a portable electrical magnetometer with which a set of readings could be obtained in a matter of minutes. Such a device has been developed by the Dominion Observatory of Canada.

### 4. Special purpose surveys

Further development of instruments is required in order to be able to define the magnetic environment of an area. In part, existing instruments have been found to be unwieldy in operation. New gradiometer equipment is currently under development and should overcome the deficiencies of the present instruments. A magnetic temporal variation recorder must be developed to meet existing requirements. Equipment for this purpose is not currently available.

## H. RECOMMENDATIONS

### 1. Airborne geomagnetic surveys

The short-term instrumentation program for airborne surveys should be directed towards satisfying several present deficiencies in such a way as to reduce manual operations, obtain maximum reliability, and yet utilize available components wherever possible. In this connection, it is recommended that the Hydrographic Office:

a. Develop and construct a low-drift voltage standard for use in the VAM total intensity circuit; also evaluate the silicon zener

diode voltage reference element to determine the feasibility of using it to replace the mercury batteries and standard cells presently required.

b. Design and develop a precise current control system for the VAM incorporating automatic base line indexing and both analog and digital recording of data.

c. Design and construct a new mounting base and gimbals for the VAM detector. These would improve the reliability of declination measurements by preventing small azimuth reference errors in the VAM due to vibration, shock, roll, and pitch.

d. Develop a system for automatic magnetometer data recording. This system should be directed towards satisfying computer input requirements and have sufficient flexibility to provide for increased accuracy at a future date.

e. Develop and procure a portable recording magnetometer suitable for field use. This instrument, used in the survey area, may be useful for evaluating survey flights, particularly in auroral regions where large short-period fluctuations are not infrequent.

Magnetic data of higher accuracy than currently achieved doubtless will be required throughout the world. Toward this end, it will be necessary to utilize somewhat more sophisticated instrumentation. To obtain more accurate data on the direction of the magnetic field, it will be necessary to employ an accurately stabilized platform as a frame of reference. Additionally, it will be necessary to obtain precise, absolute measurements of the field strength, possibly with a nuclear precession or alkali vapor magnetometer. The accuracy of survey navigation must be improved before any significant increase in survey accuracy can be achieved with new magnetometer equipment. To achieve such longer range objectives, it is recommended that the Hydrographic Office:

f. Support the development of an improved airborne vector magnetometer of greater precision than existing instruments. One approach to this problem lies in adopting an overall system viewpoint for the magnetic airborne survey. Treated in this way, the survey system can be broken down into six subsystems: (1) Navigation subsystem to provide astronomic position, directional and vertical references, ground velocity, and time; (2) magnetic vector subsystem to provide direction and intensity of the magnetic field; (3) magnetic

compensation subsystem to generate a region within the aircraft wherein the effects of the magnetic field of the aircraft are minimized; (4) flight control subsystem to provide autopilot control signals to permit making good a predetermined survey track; (5) computer subsystem to integrate the subsystem elements, provide read-in and read-out functions, provide fail-safe operation, and permit alternate modes of operation under certain failure conditions; and (6) recorder subsystem to provide a permanent record of all vital survey data.

g. Support the development of precise, absolute total field magnetometers for airborne applications.

## 2. Marine geomagnetic surveys

It is recommended that the Hydrographic Office:

a. Continue work on the improvement and simplification of the nuclear precession magnetometer and towing system.

b. Support development of the rubidium vapor magnetometer for both total field and gradiometer operation. This instrument will be useful both for shipboard surveys and for fixed location, temporal variation measurements.

c. Fully exploit the movements of survey ships under the control of the Hydrographer by employing towed total field magnetometers routinely.

d. Support an investigation of more efficient data reduction and presentation procedures and instrumentation.

## 3. Land measurements

It is recommended that the Hydrographic Office support the development of compact, portable instruments for field measurements of magnetic field direction and intensity.

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## XV. POSITIONING

### Engineering Section Survey Branch

#### A. ANGLE AND DISTANCE MEASURING INSTRUMENTS

##### 1. Introduction

The geodetic surveys of the Hydrographic Office are made to establish the control for various other types of surveys. The field work varies according to the accuracy requirements of the work for which the control is being established. The work also varies according to whether it is: (1) The extension of an existing control by means of triangulation, trilateration, traverse, or a combination of these; or (2) the establishment of an independent datum, as is usually the case in isolated areas or on remote islands, where an astronomic position is determined independently and corrected for plumb line deflection by a gravity survey, and where the local control nets are tied in.

In both types of surveys, the general specifications given in Hydrographic Office Publication No. 4 and USC&GS special publications are followed but are modified by the specific requirements for each field project.

Until recently, standard survey practice consisted entirely of measuring angles with a theodolite and measuring distances with a tape, subtense bar, or stadia rod. Today, the picture is changing rapidly. Although the theodolite is virtually unchanged, the older instruments for measuring distance are being replaced with new electronic devices that make the job easier, faster, and more economical.

The instruments available in the Hydrographic Office for field surveying consist primarily of theodolites, conventional measuring devices, the geodimeter, and the tellurometer. The capabilities of these instruments are presented below.

##### 2. Angle measuring instruments (theodolites)

In a field survey, all angles, horizontal and vertical, are observed with a theodolite, usually a Wild theodolite manufactured by the Henry Wild Company, Heerbrugg, Switzerland. This is an optical micrometer-reading instrument in which two diametrically opposed axes are brought to coincidence and read through a microscopic eyepiece. The various

models are accurate, compact, and easily portable and stand up well under handling and rugged field conditions. Plates, optical units, and other delicate parts are enclosed to protect them from rough handling, water, and dust.

a. T-2 theodolite

Because of its good accuracy and ease of handling, the T-2 theodolite has become the one most frequently used. It is good for ordinary survey work of third-order accuracy. With the exercise of care and the use of proper daylight conditions and signals or lights at night, second-order accuracy is possible. Angles can be read to one second and estimated to 0.5 second. An astrolabe, or polar attachment, makes it possible to do astronomical work with fair accuracy. Azimuths can be determined to within one second of arc. An eyepiece for centering the T-2 above the station mark is provided. Lighting attachments and battery boxes make the instrument usable for night observations. The lenses have been improved from time to time to give clearer images and improved visibility over long lines, but the length of the line generally is limited to about 10 to 12 nautical miles. The weight of the theodolite is 12 pounds, and that of the container 5 1/2 pounds. The cost of the T-2 alone, without tripod or accessories, is approximately \$1,400.

b. T-3 theodolite

This is a larger model of the T-2 theodolite with which better accuracy is obtainable, but at the expense of portability and ease of handling. The T-3 weighs about 24 pounds and is not as easily transported in the field as the T-2. However, it still is considered portable and rugged enough to be a good field instrument. Where greater accuracy is needed, the T-3 usually is chosen. It is used for primary triangulation or basic control for geodetic work. The circle can be read to 0.2 second. Triangle closures of less than one second are common. With the proper accessories such as the eyepiece prisms and astrolabe, good astronomical work can be done. Three eyepieces of different magnification are supplied with the instrument, and each is used depending on the weather. In heavy haze the 24-power eyepiece is used; in medium haze, the 30-power eyepiece; and with little or no haze, and for astronomical work, the 40-power eyepiece is used. Lines 25 to 30 nautical miles in length can be observed without difficulty. The T-3 can be purchased for about \$2,500; accessories cost an additional \$500.

### c. T-4 theodolite

This is the largest and most accurate of the Wild theodolites. It is built primarily for astronomical work and is capable of precise azimuth determination. The T-4 is a broken-telescope type of transit in which the eyepiece is at the side and always horizontal so that the tilt of the telescope in no way impedes the sighting. It can be used for all well known methods of astronomical determination of position. Such use involves other units, however, and is not accomplished with the T-4 alone. Astro observations are taken with the T-4, chronometer, and radio receiver, all connected to a chronograph which records on tape the data from all three sources. The theodolite marks the time of transit of a star; the chronograph provides local sidereal time; and the radio supplies time signals from the National Bureau of Standards. Breaks in the electrical contact are made by time ticks and transit marks and show on the tape in their proper order. This system gives a reliable radio-chronometric comparison to provide the necessary accuracy of position.

The total weight of the T-4 and accessories is about 400 pounds, depending upon the size of the radio receiving set and generator. The T-4, itself, is shipped in two boxes: in one, the telescope weighing 88 pounds, and in the other, the base weighing 121 pounds. Direct readings can be made on the horizontal circle to 0.1 second and on the vertical circle to 0.2 second. With a sensitive suspension level and two Horrebow levels (all with scales of one second for each two millimeters), first-order astronomical positions can be obtained. The T-4 has worked well even under adverse conditions; in remote areas, difficulty in the reception of time signals becomes the most troublesome factor. Improvement in radio reception might be obtained through use of a more powerful receiver and an improved antenna. The cost of a complete T-4 theodolite, with accessories, is about \$9,000.

### 3. Levels

Vertical control for topography and to connect tide gauges to bench marks while important, is a small portion of the total field work. It is sufficient to say that vertical control can be established when needed. Wild levels, Models N-II and N-III, generally are used and, like the theodolites, are considered compact, sturdy, and accurate. First-, second-, and third-order control are possible with them.

#### 4. Distance measuring instruments

Two electronic instruments are used for trilateration and the measurement of base lines and long traverse lines. Both instruments determine distance between points and eliminate the necessity to traverse between them. The component units of both instruments are portable; the time required for a measurement is short; and the accuracy of each is high. These instruments are the geodimeter and the tellurometer.

##### a. Geodimeter

The geodimeter is a precise instrument for measuring distances by employing the known velocity of propagation of light waves. A modulated beam of light is transmitted to an unattended passive prism reflector which returns the light to the transmitter. The time interval is measured indirectly, and the distance then is computed.

Four models of this instrument are available, each having certain advantages. The first, Model NASM-1, is large and bulky and is considered unsuitable for the use except where it can be transported by vehicle; it was designed for the measurement of base lines, and for that purpose has proven excellent. The second, Model NASM-2, is more of a refinement of Model NASM-1 than a separate model. Models NASM-3 and NASM-4 are designed for field service and, as such, are compact and portable; however, with the reduction in bulk, some accuracy has been lost. All the instruments are used for line-of-sight measurements and need a power source at only one end of the line.

###### (1) Model NASM-2

This model has a maximum range of 30 nautical miles and, because of its size and weight, is used primarily for base line work and for checking lines in existing arcs of triangulation. It is made up of the two basic units, the transmitter-receiver and a reflector. The weight of the transmitter is about 220 pounds. The reflector is a group of prisms that weighs approximately 35 pounds. The disadvantages of this model, in addition to its size, are that it must have an available power source and that it must be operated at night. Power requirements are 140 watts from a 110- or 220-volt, 50- to 60-cycle current which may be supplied by a portable generator. This instrument allows a rapid set-up, and a line can be measured in less than three hours with first-order accuracy. Atmospheric conditions can affect the accuracy somewhat, especially on the longer lines. Shorter lines must be used if observing cannot be done under good weather conditions. It is possible

to use another reflector at a second station to measure a second line with only one set-up of the transmitter. Thus, it is possible to establish control nearly as fast as by ordinary triangulation methods. Because of its range and accuracy, this instrument is considered to be probably the best instrument for precise distance measurement.

(2) Model NASM-3

This model is an intermediate range instrument that can measure lines as long as 20 nautical miles and, under proper atmospheric conditions, obtain second-order accuracy; on shorter lines, it is easier to obtain such accuracy. Some accuracy is lost, compared to the NASM-2, but greater mobility is gained. Two sizes of reflectors are supplied; for shorter lines, the smaller ones can be used to observe more than one line at a time. For longer lines, one large reflector, or a group of the smaller ones, is used at one station. The NASM-3 weighs 57 pounds and a reflector 10 pounds. The weight, being about one-quarter that of the NASM-2, makes it possible to set up this instrument and measure distances more rapidly; a line can be measured in about one hour. This instrument is considered rather small for accurate base line work and rather heavy for ordinary traverses; however, it performs well on long traverse lines and on trilateration. The NASM-3 requires about one-half the power supply of the NASM-2 and may be operated by 6-12-24-volt batteries.

(3) Model NASM-4

This instrument is portable and fast, but has a limited range and only fair accuracy. It weighs 35 pounds, but requires another 50 pounds of power supply and tripod. It operates from a 6-12-24-volt battery through an inverter or from any 110-volt line. The NASM-4 has a normal range of three to five nautical miles and commonly provides third-order accuracy. Any number of lines may be measured for any given set-up depending upon the number of points marked with reflectors. The two sizes of reflectors weigh only three and four pounds and may be spotted as desired. It is possible to set up and measure a line in 15 or 20 minutes. This instrument is used mostly for short line traverse work. Evaluation by the U. S. Army Engineer Research and Development Laboratory (ERDL) indicates that under exceptional conditions lines as much as 11 nautical miles long may be measured with results that meet the standards of first-order accuracy.

b. Tellurometer

This instrument is manufactured and sold by Tellurometer

Ltd., Capetown, South Africa and has been on the market since 1957. It has made possible, for the first time, a means of measuring distances accurately with a small portable unit usable in the field. The tellurometer is an electronic device that uses the pulse type system and consists of two units, the master and the remote. A pulse of radio-frequency energy is transmitted to the remote unit, analyzed, and transmitted back to the master unit. The interval between signals is read in successive steps as millimicroseconds and recorded. The trace appears as a circle on a calibrated graticule which covers the face of a cathode ray tube. The velocity of propagation of the wave is known, and the distance is merely one-half the product of the tellurometer reading and the propagation velocity. Weather conditions affect the velocity and are taken into account, by a slight correction made in the computed distance. Altimeter readings are taken, or vertical angles read, to determine elevation differences since the tellurometer gives the slant distance only.

This is a line-of-sight device that operates on 3,000 megacycles. On the face of each unit are a cathode ray tube, switches, and meters; the back of each unit has a parabolic antenna. One man can operate each unit, but since all the readings are taken at the master unit, time is saved if one man reads and another records; a man at the remote unit merely switches frequencies. Each unit weighs 38 pounds, and the power pack, storage battery, and tripod account for another 35 pounds. A set-up can be made, several readings taken, and the instrument repacked in about 30 minutes. Readings may be made night or day and in fog or damp, cloudy weather. Rain and snow prevent accurate readings, but this disadvantage is not considered significant. As with the geodimeters, the power source is a troublesome aspect when the batteries have to be carried any great distance.

Lines that appear to be accurate often prove to be inaccurate because of interference from objects below or along the line. Thus, experience is required to know just how to avoid inaccurate lines. Often, movement of either unit a few feet eliminates the trouble. The maximum range is 38 to 40 nautical miles with first-order accuracies obtainable in the longer lines by virtue of measurement of longer time intervals. For short lines of two miles or less, measurements approach second-order accuracy. With two or more remote units, several lines can be measured in a short time. The cost of one set, both master and remote units, is approximately \$9,000.

#### c. Microdist

This instrument system is similar to the tellurometer in

operation and construction, but it is new and has not been fully evaluated as yet. The microdist consists of two units and operates on the interrogator-responder principle, but the responder transmits a return signal with a different modulation. Either instrument may be used as an interrogator or responder. Each unit weighs 35 pounds. The system has a maximum range of about 50 nautical miles and a stated accuracy of three parts per million  $\pm 1$  inch. It needs a 12- or 24-volt battery for power. The crystal calibration is automatic, a feature not found in the earlier models of the tellurometer. Certain modifications and more testing remain to be done before this instrument is ready for actual survey use. It appears to be easier to operate than the tellurometer, but is bulkier and more difficult to transport in rough country. Manufactured by the Cubic Corporation of San Diego, California, a complete system costs about \$12,000.

#### d. Miscellaneous instruments

The Motorola Corporation and W. & L. E. Gurley Co. both have instruments similar to the tellurometer and microdist that are not yet available. The Motorola model is completed and undergoing tests at present. The amount of modification and retesting necessary before it is ready for use is not known. The Gurley model is not as yet ready for testing. ERDL has an extensive development program underway which includes airborne tellurometers, automatic tracking theodolites, and electronic computers.

### B. ELECTRONIC POSITIONING SYSTEMS (NAVAIDS)

#### 1. Introduction

A number of different electronic positioning systems are treated separately from the other electronic measuring devices used in surveying, because these systems are designed to determine a position in space rather than to measure an angle or a distance, although they also may make one or the other of these measurements. As in all electronic systems, they are based on the principle of measurement of travel times of electromagnetic waves.

Since the propagation velocity of radio waves is, nominally at least, a constant, the several systems differ among themselves in the frequency used, the type of transmission used (continuous wave or pulsed wave), and the types of lines of position produced. The electronic positioning systems may be divided into four general types on this last basis: hyperbolic systems, such as Lorac and Loran; ranging systems, such as Shoran and Lambda; azimuthal systems, such as

Consol and the new Canadian microwave position fixing system; and composite systems, such as the latest Raydist (a combination of both hyperbolic and ranging systems). Each of these systems is discussed briefly.

## 2. Hyperbolic systems

### a. Lorac (LOng Range ACCuracy)

The Lorac, built by Seiscor, a division of Seismograph Service Corporation, is a continuous wave, phase comparison, hyperbolic system that uses three shore stations and permits an unlimited number of users. It uses frequencies in the vicinity of two megacycles. The useful range is about 200 nautical miles, and accuracies range from about 15 feet on the base line to about 400 feet at the outer limits of the usable area.

The shore equipment consists of four transmitters and two receivers and establishes the hyperbolic lattice by using two pairs of frequencies with an audio "beat" frequency of 315 cycles between the two frequencies of the red pair and 135 cycles between the frequencies of the green pair. The red, center, and green stations should be established at about 60 to 120 miles apart, with the angle between the two base lines preferably less than 135° and preferably with the triad concave toward the area of interest. A position is read from the phase meters of the shipboard receiver in the red and green "lanes." A lane is a half-wave length which is roughly 230 feet wide (depending upon the frequency being used) on the base line.

As the hyperbolic lines of position depart from the base line they spread apart, so that as the outer limits of the service area are approached, a lane has expanded to some 1,380 feet in width. In other words, the accuracy degenerates with distance from the shore stations: a phase reading error of 0.01 lane equals about a 2 1/2-foot error on the base line but becomes about a 14-foot error near the limits of the service area. The accuracy is also dependent upon the angles of intersection of the lines of position; as long as these are between 15° and 165°, the system is adequate. It is highly desirable that there be a minimum of overland transmission between the stations of a triad and between the stations and the service area, because such transmission seriously degrades the accuracy and effectiveness of the system.

The hyperbolic lattice can be computed and laid out on plotting sheets so that the lane readings from the phase meters may be plotted

directly. Programs are available for a Bendix computer to transform red and green lane readings to latitude and longitude, and vice versa.

The principal disadvantage of the Lorac system is that it is very easy to lose count of the lanes. The phase meters, when once calibrated and set, determine with high accuracy the user's position within a lane; but, in order for the user to determine within which lane he is, he must go to a known point and set the proper lane count on the meters. Then, as the user moves through the area, a lane is added or subtracted from the total each time the phase meters make a full revolution. If a power failure, an electrical storm, or other interference occurs, the lane count can be lost and can be recovered only by returning to a known position and once again resetting the meters. This can be very time consuming. In addition, the shore station equipment is heavy and cumbersome.

#### b. Loran (LOng RAnge Navigation)

Several loran systems compose this family of pulsed, time difference, hyperbolic systems. These are the Loran-A, Loran-B, and Loran-C.

##### (1) Loran-A

This is a navigational system, rather than a survey system, that uses frequencies in the vicinity of two megacycles and has a maximum usable range of about 700 nautical miles. In a few instances, Loran-A and Decca (another hyperbolic navigation system similar to Loran-A) have been used in connection with Lorac or other systems for lane-count purposes. Accuracies cannot be expected to be much better than about a mile at ranges of 100 miles or more.

##### (2) Loran-B

This is a short range, high precision system having frequencies in the vicinity of two megacycles and a range of about 300 nautical miles. It is still in the experimental stage.

##### (3) Loran-C

The Loran-C is a long range, high precision system that uses phase comparison to refine the time difference measurement. It has frequencies in the vicinity of 100 kilocycles and a range as

great as 1,200 nautical miles. The Loran-C is the only loran system now in use by the Hydrographic Office for survey work.

When the present experimental equipment incorporated into the Loran-C system has been made more reliable, it is expected that the system will have a repeatability on the order of about one foot per mile of distance from the shore stations. It is, however, very sensitive to distortion from overland transmission and requires a sophisticated calibration procedure to determine predictability and overall system accuracy. Another drawback is the large and complex shore installation required, which includes a 625-foot transmission tower. It is considered that the system is not well adapted for use at scales larger than 1:50,000.

### 3. Ranging systems

#### a. Shoran

This is an interrogator-transponder system that uses the UHF band (200 to 300 megacycles). The range is restricted to approximately line-of-sight distances, but good accuracy is available to several users. Position is determined by measuring the time required for the high frequency signal to travel from the mobile station to the transponder and return. Two fixed, shore stations are required, and several mobile stations can use the same two fixed stations. Lines of position are concentric circles. Accuracies on the order of 30 to 50 feet and ranges as much as about 40 nautical miles can be obtained depending upon the elevations available for the shore stations. This system is not particularly sensitive to distortion caused by overland transmission.

#### b. Electronic Postion Indicator (EPI)

This system is an interrogator-beacon system that uses either 1,850- or 1,950-kilocycle frequencies. It requires a mobile master station and two fixed shore stations. Position is determined by measuring the time required for the signal to travel from the mobile master to the shore station and return. Two mobile master stations may use a pair of shore stations on a time-sharing basis. The obtainable range is from 12 to 400 nautical miles, and the accuracy ranges from about 135 feet in the best part of the area to about 1,500 feet near the outer limit. The lines of position are concentric circles. Although the system requires continual calibration, it is considered to be excellent for exploratory surveys but should not be used at scales larger than 1:80,000. The distance measured between the master and a shore station must

be checked at least once a week by determination of the ship's position by visual means or Shoran; experience has shown that changes in the calibration factor on the order of several microseconds can be expected from time to time. The system also is sensitive to land masses along the transmission path, which can cause extremely erratic readings.

#### c. Lambda and Two-Range Decca

These systems are a development of the standard navigational Decca by the British corporation, Decca Navigator, Ltd. and are fundamentally the same. The Lambda has a range of about 250 nautical miles and an accuracy of 100 to 400 feet. In both, the master station is the mobile user, and two shore stations are the slaves. Measurement is always along the base line. Only one vessel can use these systems at a time, except by time-sharing with others. Each of the two master-slave pairs radiates on a different frequency, since, if all three transmitters radiate on the same frequency, phase comparison is impossible. However, the frequencies are related so that a common harmonic can be generated within the receiver in order to compare the phases. The fundamental frequency,  $f$ , lies between 14 and 15 kilocycles per second. In both systems, the red slave transmits at  $8f$  and the green slave at  $9f$ . The master station uses  $12f$ , and the comparison frequencies are  $24f$  and  $36f$ . The principal difference between the Lambda system and the Two-Range Decca System is that the Two-Range Decca System has the same lane ambiguity as Lorac, whereas the Lambda System provides a means of lane identification.

Both the Lambda and Two-Range Decca Systems require calibration before use. This can be done by moving the mobile master station (the ship) into visual range of one of the shore stations, positioning the ship with three simultaneous theodolite fixes, computing the position and then the distance from shore, and using the distance to determine the calibration constant for that pair of master and shore stations. A more satisfactory technique is being developed in which a tellurometer will be used to measure the distance directly with a considerable saving of time and effort, especially in areas of fog and poor visibility. The Lambda and Two-Range Decca shore stations must be located within 1,000 feet of the coast to avoid signal distortion resulting from overland transmission; any appreciable land mass along the transmission path will create a "shadow" area of poor positioning.

#### d. DM Raydist

This is a system very similar in principle to the British Lambda system, and it has the same number of component stations.

It is produced by the American firm of Hastings-Raydist, Inc. Two types are available: a large 100-watt system having a range and accuracy considered comparable with Lambda, and a miniaturized 10-watt system having a range to 25 nautical miles and high accuracy. The miniaturized set has the great advantage of being truly portable and offers the solution for localized inshore surveys. The two systems, large and miniaturized, are compatible so that they can be used interchangeably. The large system has been used by both the Coast and Geodetic Survey and the Hydrographic Office with satisfactory results. The smaller system is not yet available for evaluation.

#### 4. Azimuthal systems

No azimuthal systems are currently in use by the Hydrographic Office. Consol is a European system of value only for navigation. The Canadian microwave position fixing system has been evaluated by the Coast and Geodetic Survey, but has not been tested by the Hydrographic Office. No final report on this system has been received yet from the Coast and Geodetic Survey.

#### 5. Composite systems

Although no composite system generally is being used by the Hydrographic Office, a combination of one hyperbolic line of position and one Shoran station was established to control operations around an island where insufficient distance was available to allow setting up a Lorac net. Also available is a Raydist system which will do substantially the same thing with only two shore stations instead of three. This system has not yet been evaluated by the Hydrographic Office.

### C. CONCLUSIONS AND RECOMMENDATIONS

RDT&E funds have been requested for FY 1962 to accomplish work on improved positioning methods and instruments. Some comments on particular instruments are given below.

#### 1. Angle measuring instruments

The optical instruments are well standardized, have good capabilities, and are well adapted for the work. Even with the many changes in survey techniques, it is considered that the various theodolites will be hard to replace as mapping moves farther into remote areas. It is expected that any changes in these instruments would be minor.

## 2. Distance measuring instruments

### a. Geodimeter

It appears that a need will exist for either increased range and accuracy in the Model NASM-4 or a decrease in the size of the Model NASM-3. The Model NASM-4 is considered somewhat limited in its performance, and it is felt that a single instrument combining the advantages of these two models would be desirable.

### b. Tellurometer

Changes already have been made in the tellurometer, and a new, improved, militarized model is available. The reflector has been improved, and a vibrapack has been incorporated into the set itself. However, the power source remains bulky and bothersome. New batteries that are smaller, more powerful, and leakproof are available and have helped somewhat. It is considered that easier (numerical) dial reading and automatic crystal calibration could well make the instrument easier to operate.

Results were difficult to obtain from the tellurometer during the first months of its operation, and it was felt at the Hydrographic Office that the instrument was mostly at fault. However, further use in two years of field work has shown that the results obtained from the instrument improve with the greater experience of the operator. Most of the present reports indicate the need for several weeks of training before an operator can get maximum results from the instrument.

## 3. Electronic positioning systems

A number of new, high accuracy, short range systems, such as Hi-Fix by Decca, HYDRO-DIST by Tellurometer, and EMPE by Cubic Corporation, are being put on the market. It is recommended that these systems be studied and evaluated. It is recommended further that better calibration techniques be developed for the long range systems, such as Loran-C.

The work already done with ranging systems indicates that the limiting factor is the range of adequate reception rather than the system geometry that is the limiting factor with hyperbolic systems. It also is recommended that research be aimed toward developing a precision ranging system that would have ranges on the order of 600 to 800 miles or more.



## XVI. WINCHES AND HOISTS

Edward W. Johnson

### A. INTRODUCTION

Until quite recently oceanographers in the field were forced to rely upon or modify whatever machinery was at hand in order to anchor their survey vessels and/or to lower sensing and sampling gear. This situation was caused principally by the lack of sufficient funds to provide adequate winches and hoists tailored to the operation in question. Recently, as a result of the greater demand for oceanographic information, specifications for particular winches and hoists have been and are being prepared, and some new equipment has been built. The winches and hoists used in oceanographic investigations are of four types: deep sea anchoring winches, oceanographic survey winches, electric cable reels, and bathythermograph hoists.

### B. DEEP SEA ANCHORING WINCHES

Initially, in 1949-1950, both the USS REHOBOTH and the USS SAN PABLO (Hydrographic Office survey vessels) were outfitted with modified minesweeping winches which had capacities of approximately 25,000 feet of one-half inch wire rope that enabled anchoring in depths of 2,000 fathoms (assuming the normal 2:1 scope). These winches were fantail installations, and anchoring was accomplished over the stern.

In 1956, the minesweeping gear was removed from the REHOBOTH and replaced with an LST 1153-class steam anchoring winch, manufactured by the Clyde Iron Works of Duluth, Minnesota. This installation, twelve feet by twelve feet by seven feet in size, had a capacity of approximately 35,000 feet of one-half inch wire rope and increased the deep mooring capability of the REHOBOTH by about 650 fathoms. In addition, handling characteristics were much improved, and anchoring was accomplished by a fair lead forward over the bow.

The SAN PABLO in 1957 had her minesweeping gear removed, and the deep sea anchoring winch from the GALATHEA (purchased from the Danish Government in 1955 at a cost of \$25,000) was installed upon the removal of the number one gun turret. The GALATHEA winch is unique inasmuch as it has two drums, one drum powered to lower and hoist the cable and a second stowage drum under tension but unaffected by stress during lowering and hoisting operations. This type of

winch had been used previously by both Swedish and Danish oceanographic survey vessels. (After unsuccessful attempts were made by the Scripps Institution of Oceanography to purchase this type of gear from Denmark, a similar winch was built from the GALATHEA specifications and installed aboard the SIO Research Vessel, SPENCER F. BAIRD. This winch was built by the Levern Manufacturing Company of Los Angeles, California.) The GALATHEA installation, originally designed for wire tapered from 12 to 22 millimeters in multiples of two millimeters for the maximum length to strength relationship, also provides for a capacity of 40,000 feet of one-half inch wire rope. Lowering can be accomplished in one hour to 2,000 fathoms.

The design of deep sea anchoring winches varies with each type of ship. Experience has shown that for oceanographic work beyond the Continental Shelf such winches should have adequate capacity for mooring in depths of 1,000 fathoms or greater.

#### C. OCEANOGRAPHIC SURVEY WINCHES

The winches in this category include all the machinery for completing oceanographic casts aboard survey vessels and are composed primarily of Wheeler (Philadelphia, Pa.) or Lakeshore (Iron Mountain, Mich.) designs. Both types of winches are electrically powered with 440-volt, 3-phase, 60-cycle current but differ in methods of control: The Lakeshore type has an eddy current coupler, and the Wheeler type is hydraulically controlled. Any speed from zero to a maximum of 350 feet per minute is available on either unit. The capacity of each winch is approximately 20,000 feet of 5/32 inch wire rope. Eight Wheeler and four Lakeshore winches have been purchased and placed aboard various U. S. Navy survey and auxilliary vessels.

The oceanographic winches aboard these vessels are designed for multi-purpose use, that is, for oceanographic casts, trawls, dredges, bottom samplers, current meters, and special water samplers. They are "over-designed" to provide adequate power for lowering and hoisting all instruments used by the Hydrographic Office and, thus, are functional but expensive (\$20,000 each).

The winches used by private institutions conducting oceanographic research usually are designed for single purposes such as making oceanographic casts and lowering multi-conductor instruments. As a result, the winches are smaller and less expensive but do not provide as wide a selection of operational uses as do the Navy units. This trend toward specialization reduces the cost of individual winches, but several winches are required to complete the tasks that can be handled by one Navy winch.

Additional requirements for part-time oceanographic operations in deep water brought forth the design of a portable oceanographic survey winch. Six of these winches, designated WOE 7.5, were manufactured by the Western Gear Corporation of Seattle, Washington for this Office. Each winch is mounted on a prefabricated bedplate that has an attached working boom to simplify the installation. The power requirement is 230 volts d.c., and a portable generator may be used if power is lacking in the field. This winch has a designed capacity of 8,000 feet of 5/32 inch wire rope and can lift a 1,000 pound load at an average speed of 225 feet per minute. By overloading the drum, the capacity can be increased to 14,000 feet of 5/32 inch wire rope.

#### D. ELECTRICAL CABLE REELS

Originally, the primary requirements for electrical slip-rings, or other methods of electrical continuity through a winch, were those dictated by the Roberts current meter design. Both the USS REHOBOTH and USS SAN PABLO were outfitted fore and aft with hydrophone winches manufactured by the Silent Hoist and Crane Company of Brooklyn, New York. Both installations are electrically powered with 440-volt, 3-phase a.c. current and are two-speed, reversible winches capable of handling 3,000 feet of .310 electrical cable. The cable used is US Steel type 3H1 and contains three electrical conductors; the conductors are not insulated. Each winch has three slip-ring conductors that provide electrical continuity from sensor to recorder. These winches are slow and electrically very noisy and require constant maintenance because of their age.

With the advent of the electronic bathythermograph, sound velocity meter, and sensitive current measuring instrumentation, specific design requirements for a more efficient oceanographic winch were formulated. The series-600 electrical cable reel was manufactured to these requirements by the Commercial Engineering Corporation of Houston, Texas and received by this Office in December 1959.

The series-600 electrical cable reel is designed for a maximum capacity of 8,000 feet of .310 six-conductor, electrical cable or 12,000 feet of .190 six-conductor electrical cable and has six slip-rings integral with the drum shaft. By a combination of multiple brakes, a differential gearing system, and an air-coupling energy absorber, all controlled by a single lever, the operator has the selection of any speed from zero to a maximum of 350 feet per minute. All motor controllers are housed within the frame, and the reel is engineered for quick (20 minutes) changing of drums. The gross weight of the unit

is approximately 3,800 pounds, and its over-all dimensions are 55 inches by 52 inches by 58 inches. A series-600 electrical cable reel was installed aboard the USS SAN PABLO in February 1960.

#### E. HOISTS

This category is comprised of light-duty reeling machinery, specifically the BT hoists, which are aboard all survey vessels of the U. S. Navy and other agencies and utilized for many purposes. The BT hoist is a line-produced item and comes in many models differing primarily in power requirements. All models have essentially similar operating characteristics, that is, a capacity of 2,000 feet of 3/32 inch wire rope, free wheeling during lowering, and a hoisting speed of approximately 300 feet per minute at lower ship speeds. Until 1953, all models were of the E-2 side-drum construction, but to date practically all of these have been replaced with the E-6 center-drum model. In addition, with the added importance of thermostructure data to antisubmarine warfare that necessitates BT measurements to 900 feet as against 450 feet as previously established, the Bureau of Ships recently has contracted for an improved model with greater wire capacity (3,000 feet) and better operating characteristics.

A new model hoist, the series-200 hoist, also was constructed for the Hydrographic Office by the Commercial Engineering Corporation. This hoist, a smaller version of the series-600 reel, is engineered as a component of the electronic BT system and is built to handle 3,000 feet of .190 electrical cable. It also has a single lever control, six slip-rings, interchangeability of drums, and an eddy current coupling which slips as the brake is applied, thus enabling use of any speed within the speed range. This hoist is a "packaged" model that has an attached A-frame reaching outboard nine feet from the hoist. The gross weight of this unit is approximately 1,140 pounds, and its dimensions are 25 inches by 24 inches by 38 inches over-all. One unit of this series also has been installed aboard the USS SAN PABLO and has given excellent results to date. In addition, one of the series-200 hoists has been installed aboard a USCG weather ship and is being used to collect data for the Hydrographic Office.

#### F. CONCLUSIONS AND RECOMMENDATIONS

Emphasis on synoptic oceanography will increase the requirements for portable oceanographic winches. Simplicity of installation is an important design criterion since these winches must be shifted from vessel to vessel.

The increased use of electric and electronic sensors makes it necessary to develop improved electrical cable reels. High capacity drums, better electrical slip-rings, and more slip-rings per winch are desirable features of future designs.

It is recommended that performance specifications be prepared for several winch and reel designs.

#### 1. Portable oceanographic winches

a. A portable oceanographic winch should be designed with two-speed control, a capacity of 15,000 feet of 5/32 inch wire, and a maximum gross weight of 2,500 pounds.

b. Also required is a portable winch with two-speed control, a capacity of 5,000 feet of 3/32 inch wire, and a maximum gross weight of 1,000 pounds.

#### 2. Electrical cable reels

A cable reel is required that has an a.c. electric motor, variable speed control, a capacity of 10,000 feet of 0.4 inch eight-conductor wire, ten slip-rings, and an optimum gross weight of 3,800 pounds. Development of this reel is needed immediately.

#### 3. Hoists

A portable BT-type high-speed hoist is needed having a variable speed control, a capacity of 3,000 feet of 0.2 inch three-conductor wire, five slip-rings, and an optimum gross weight of 900 pounds. Development of this hoist should parallel the work on the smaller cable reel mentioned above.



## APPENDIX A. FIRST PROGRESS REPORT

Code 5401-BEO/klw  
22 April 1958

### MEMORANDUM

From: Committee on Instrumentation

To: Deputy Hydrographer

Subj: Committee on Instrumentation; progress report of

Ref: (a) Code 1000-bla memo of March 5, 1958

Encl: (1) Report of subject Committee on Oceanographic and  
Hydrographic Instrumentation

1. Despite extended absences of several of its members, the Committee established by reference (a) has met four times since its inception.

2. Enclosure (1) summarizes the approach of the Committee to its assignment. Responsibilities for assembling information on instrumentation in different areas have been assigned to Committee members. Considerable time has been devoted in Committee meetings to indoctrination of the members on instruments and requirements in fields other than their own. A form has been designed for summarizing data on instruments and components regarded as worthy of serious consideration. It is intended that this form will be revised after an adequate trial run.

3. It has become apparent that, if the Committee's work is to be significant, considerable time must be devoted to seeking out details on the performance of particular instruments and components. It is believed that this could be accomplished most effectively by working closely with the Instrumentation Division. The Committee also feels that it would be highly desirable to have direct access to someone capable of checking by pilot study, or his knowledge of electronics, the intermediate steps or tentative conclusions of the Committee in developing recommendations for systems. For these purposes, it is requested that someone at the working level in the Instrumentation Division be assigned to work closely with the Committee. It is felt that someone with a good knowledge of electronics, imaginative, and willing and able to do "bench work" would best be able to fulfill the requirements anticipated by the Committee.

BOYD E. OLSON  
Chairman

# OCEANOGRAPHIC AND HYDROGRAPHIC INSTRUMENTATION

## INTRODUCTION

There are innumerable approaches to the task of evaluating instruments and systems for data recording, conversion, and storage. A rigorous evaluation and comparison of the performance characteristics of all instruments now in use in the fields of oceanography and hydrography would require many months of exhaustive laboratory and field testing. At the same time, it may be obvious from the outset that many of these instruments do not warrant serious consideration for future use. On the other hand, selection of only certain instruments for test and study may result in serious oversights unless it is approached systematically. To resolve this dilemma and to bring the problem within manageable scope, the Committee tentatively agreed upon the following approach:

1. Identify or conceive desirable systems that can be assembled from existing components. Such systems concepts are to serve as the framework for more detailed evaluation of existing systems, instruments, components, and elements. (It is recognized that not all measurements lend themselves to such systematization.)
2. Summarize performance characteristics of existing instruments, components, etc. for evaluation and comparison.
3. From the foregoing and such outside consultation as is necessary, recommend the development or modification of a specific system or sub-system at an early date. This development project would serve as a pilot study and should proceed concurrently with the other work of the Committee in order to test the validity of its conclusion and to point-up the practical problems concomitant with instrumentation development.
4. Continue to collect information on new instruments and concepts and make further recommendations for instrument purchases, development, and testing based on this information.
5. Make recommendations for exhaustive reliability tests of equipment currently in use, as deemed necessary.

The problem, guides, factors to be measured, and stages involved are outlined as follows:

## ASSIGNMENT

Examine and make recommendations for: An orderly program of modernization of instruments for field measurements of all forms of geophysical data of interest to the Hydrographer, associated data recording and conversion devices necessary for use either in the Office or the field, and the methods and form of storage of this data.

## GUIDES

1. Apply established engineering principles and components which have been developed in other fields. Aim for improvements in accuracy, ease of operation, consistency, and decreased time at all stages of operation.
2. Contact civilian and governmental activities and laboratories.
3. Consider the nature and amount of data in question and the computation process it will undergo.
4. Prepare practicable timetable.
5. Retain equipment in use where practical, and specify proven equipment or components otherwise.

## FACTORS TO BE MEASURED

1. Position
2. Range (acoustics work, visibility, electrical and magnetic fields)
3. Depth (depth of instrument and depth to bottom; also depth to different layers of sediments)
4. Time
5. Oceanographic Factors
  - a. Temperature
  - b. Salinity
  - c. Conductivity
  - d. Density
  - e. Sound velocity
  - f. Sound attenuation (scattering and absorption)
  - g. Ambient noise level

- h. Transparency and visibility (scattering and attenuation)
- i. Current speed
- j. Current direction
- k. Wave height
- l. Wave period
- m. Wave direction
- n. Bottom structure (corers, grab samples, camera, television)
- o. Ice (thickness, temperature, hardness, etc.)

## 6. Other Geophysical Factors

- a. Gravity
- b. Geomagnetism

## STAGES TO BE CONSIDERED

1. Sensing
2. Packaging (waterproofing, streaming, miniaturizing, etc.)
3. Transmitting (cables, winches, relays, amplifiers, oscillators, etc.)
4. Converting, recording, and storing

## SYSTEMS CONCEPTS

In first considering oceanographic measuring systems, one is immediately impressed by the large number of combinations of components possible. However, upon further examination, it becomes apparent that these are but variations of a few basic concepts.

First, instruments can be classified as those measuring some physical or chemical property in situ, and those used in collecting samples for laboratory testing and analysis. Consideration of the second group will be deferred. Measurements in situ can be made by instruments with self-contained recording devices or by instruments that telemeter the record to a ship, airplane, buoy, or land station. Telemetering instruments are of first interest.

Telemetered signals from instruments used in oceanographic measurements are at present variations of one of the following:

1. Amplitude modulated signals
2. Frequency modulated signals

### 3. Pulse width modulated signals

These signals can be acoustical or electromagnetic transmissions (including light). Most oceanographic measurements are telemetered electrically or acoustically at the present time.

An amplitude modulated signal is a time analog, in that it is continuous rather than incremental. Inasmuch as the electric current is dependent upon the resistance of the transmitting cable, variations in the current must be measured relative to some standard level at the signal source. Strictly speaking, a frequency modulated signal is incremental in that it is a frequency count covering a very short period of time. For practical purposes such signals generally can be regarded as analogs when appropriately recorded. Thus, they have the advantage of easy conversion to analog or digital form. Pulsed signals are by definition incremental but may be made to simulate an analog. Frequency and duration of pulses may be significant.

### ANALOG VS DIGITAL

If it is necessary to choose between instruments giving analog or digital records, several things should be considered. Digital data may reduce the length of the record but sacrifice details and flexibility. Digital data may be sampled at temporal or spatial intervals, or at intervals of some other variable such as salinity, light intensity, pressure, etc. Digital data also may be obtained from analog data at any point in the data sampling, relaying, processing, or storing operation; the reverse is not necessarily true.

The ideal system is one that permits selection of analog data or a variety of digital information at any point in the system. Initially, it appears that a pulse width or FM system most nearly approaches such an ideal.

One such system is that designed at the Scripps Institution of Oceanography for telemetering temperature and depth data over a single, insulated, steel cable. The transmitted signals fall within the audible frequency band. Separate segments within this band can be used for transmitting data from several sensing elements simultaneously, such as temperature and depth. Such data can be recorded directly on magnetic tape, possibly with some preamplification necessary. It is believed that a simple counter could be built into the magnetic tape recorder to be used for monitoring to insure that the signal is being recorded properly. This system would be a simple, portable one to which components and modifications could be added for recording data directly on paper tapes,

punched tapes, or even punched cards. Inasmuch as the system would be geared to signals within the audible frequency range, it would appear that it also could be readily adapted to receive acoustic signals transmitted through the water.

In summary, the apparent advantages of this system requiring further investigation are:

#### 1. Accuracy and Ease with which Signals Can Be Relayed

Inasmuch as the signals are not amplitude-dependent they are not dependent upon the resistance of the transmitting cable. It would appear that radio transmission also would be accurate and easy. Additionally, signals could be transmitted through water along a single, insulated, steel cable, or acoustically from transducer to hydrophone.

#### 2. Flexibility in Converting and Recording Signals

The signal can be recorded directly on single-channel magnetic tape for direct analysis, for later conversion to visual display, or for digitizing on paper tape, cards, or multi-channel magnetic tape for computer analysis. Since the signal code is not in terms of current or voltage, simultaneous recording in more than one form is possible without the need for precise voltage controls. Simply by recording intermittently, sampling at any desired interval can be programmed. Choice of digital or analog data also is possible at any point.

#### 3. Simultaneous Transmission of Several Elements by Selection of Appropriate Band-Widths

With a range in frequency from 50 to 15,000 cps and the assumption that frequency can be determined to an accuracy of 1 cps, a single parameter could be transmitted and recorded to at least four significant places. Two to fifteen parameters could be transmitted and recorded to at least three significant places, and so forth. In addition, by indicating by code the type of information which follows and then staggering the parameters transmitted, and greater flexibility can be achieved.

#### 4. Direct Annotation of the Record By Voice or Code

#### 5. Availability of Methods for Converting Resistance to Frequency

This system seems ideal from the standpoint of flexibility in the choice of records, i.e., analog or digital. On the input side, conversion of resistance to frequency for a temperature sensing element can be

accomplished by a Wien bridge or other oscillator, and pressure can be converted directly to frequency by a vibrating wire transducer. Means of conversion of other types of signals also should be investigated.



## APPENDIX B. SECOND PROGRESS REPORT

Code 5401-BEO/bah  
23 July 1958

### MEMORANDUM

From: Committee on Instrumentation

To: Deputy Hydrographer

Subj: Second progress report of the Committee on Instrumentation

Ref: (a) Code 1000-bla memo of 5 Mar 1958  
(b) Code 5401-BEO/klw memo of 22 Apr 1958

Encl: (1) Summary of Progress on Evaluation of Frequency Modulated System for Measuring Water Temperature, Salinity, Depth, Transparency, etc.  
(2) Oceanographic Instruments and Systems That Should Be Developed, Evaluated, or Further Investigated  
(3) Summary Notes on Hydrographic Office Magnetic, Gravity, and Depth Measurements  
(4) Present Status of Hydro Field Instruments

1. Reference (a), which established this Committee, instructed that progress reports would be submitted as warranted by significance. Justification of this report, however, is not so much significance of the work of the Committee as it is a desire to keep in touch with the thinking of top management so as not to go too far afield.

2. With the assignment of Mr. Larry Brock of the Instrumentation Division to work with the Committee, and as a result of the efforts of others in the Instrumentation Division, the Committee has a better understanding of the problems and expected performance of the system briefly described in reference (b). This work is summarized in enclosure (1). It is hoped that firm recommendations for development of a basic system for measuring water temperature, salinity, transparency, depths, and currents can be made in the Committee's next report.

3. It is recognized at this point that any system providing the desired versatility, accuracy, and dependability will require considerable engineering. Almost without exception, it has been found that newly developed instruments that have been initially reported as glowing successes have later revealed serious defects or limitations. It is the conviction of the Committee that greater progress can be made for less money on some items by doing the basic development work

MEMORANDUM

Subj: Second progress report of the Committee on Instrumentation

at the Hydrographic Office and contracting for standard engineering and production of developed and tested devices. Mr. Brock has shown considerable skill at improving upon the existing design of an instrument. It is recommended that his efforts be supplemented by the assistance of another electronics engineer and two electronic technicians, and that this group constitute a permanent unit within the Instrumentation Division with the responsibility for developing new or improved instruments according to the general guidelines provided by a steering committee. It is expected that by the time of submission of the final report, sufficient investigating and testing will have been completed to recommend specific systems to be developed by the Instrumentation Division. Enclosure (2) lists some of the items that the Committee believes should receive early consideration.

4. In furtherance of the second interim objective of the Committee, that of summarizing performance characteristics of existing instruments, etc., a card index of available publications concerning oceanographic and other geophysical instruments of interest has been established. The work of screening and abstracting these publications is well along. In addition, more detailed evaluation sheets of instruments of particular interest have been prepared.

5. As stated in the foregoing, recommendations for specific systems will be made in the next report. At present, two basic systems for shipboard measurements are contemplated: one for water measurements (temperatures, salinities, currents, etc.) and another for other geophysical measurements (depths, gravity, magnetism, and stratification and structure of the ocean floor). In addition, longer range plans should be made for systematic instrumentation of aircraft for measurements other than magnetic. Additional consideration must also be given to miscellaneous measurements, such as plankton count and other biological sampling, bottom cores, and measurement of ice drift and thickness.

6. The fourth objective, the continued collection and evaluation of information on new instruments and systems concepts, is provided for by the card index and evaluation forms. More specific information will be obtained on some items through personal contacts.

MEMORANDUM

Subj: Second progress report of the Committee on Instrumentation

7. Recommendations for exhaustive reliability tests of equipment currently in use will be a continuing matter during the existence of the Committee; however, some recommendations can be made at this time. These include:

a. All Roberts Current Meters should be calibrated prior to use. Tests should be designed and carried out for determining the variance in measurements of these instruments and the causes of this variance.

b. An exhaustive comparison of bucket thermometer temperatures, BT temperatures, and temperatures read from some accepted standard should be made as a check on the value of the BT and the present method of processing BT slides. It is also recommended that an accurately calibrated thermometer be taken on each cruise for checking BT's and bucket thermometers. This thermometer should be checked before and after each cruise.

c. A group, either within or outside the Committee, should be assigned the task of determining the best means of obtaining accurate ranges between two ships.

8. Study of the advantages of metal-coated BT slides over smoked slides currently used has been made, and recommendations have been forwarded via the Oceanography Division to the Bureau of Ships. It is recommended that the Hydrographic Office begin immediately to use metal-coated slides exclusively. Some preliminary tests of the BT and bucket thermometer readings have been made by the Instrumentation Division. Some comparisons have been carried out within the Division of Oceanography. In addition, largely as a result of the interest of the Committee, a third and more exhaustive test of the airborne radiation thermometer has been carried out. The results of this test are still under evaluation. In general, it is believed that the Committee has aroused a greater awareness on the part of the operating people of the need for such evaluation tests.

9. No personal contact with civilian oceanographic institutions or other laboratories has as yet been made by this Committee (other than through correspondence). It is, however, expected that such contacts will be

Code 5401-BEO/bah  
23 July 1958

MEMORANDUM

Subj: Second progress report of the Committee on Instrumentation

proposed during the final phases of the work of the Committee after it has exhausted other available sources of information. Possibly one of the first visits proposed will be to the Lamont Geological Observatory to investigate a geophysical data recording system which they report as being developed.

10. Enclosure (3) summarizes the status of Hydrographic Office magnetic, gravity, and depth measurements and the nature of the instruments used. The Committee plans to examine the instrumentation problems associated with these measurements during the next phase of its work.

11. Enclosure (4) summarizes the responses received to date to a questionnaire on the adequacy of present field instruments. Not all of the questionnaires sent to the Divisions have been returned as yet.

BOYD E. OLSON  
Chairman

Summary of Progress on Evaluation of Frequency Modulated  
System for Measuring Water Temperature,  
Salinity, Depth, Transparency, etc.

Instrumentation Division

In the investigation of a device for converting a temperature change to a frequency change, one of the most promising designs studied (judging from technical reports) was that used in the Scripps telerecording BT. This unit utilized a Wien bridge type of oscillator built with two subminiature vacuum tubes and one transistor on the output stage. Thermistors were used as the sensing elements.

This circuit was breadboarded in the Instrumentation Division, and stability tests on the device showed a drift of 2 or 3 c.p.s. at room temperature at an oscillation frequency of about 1,000 c.p.s. In the attempt to improve on this stability another circuit was breadboarded. This circuit included a transistorized vibrating wire transducer amplifier made into an oscillator and showed approximately the same stability. However, during an experiment with an improved volume control (the insertion of another transistor to increase the feedback) a marked improvement in the frequency stability accompanied the improved amplitude stability. This circuit operated for a few days and drifted only 1/10 c.p.s. during this period. When the circuit was subjected to an environmental change, from room temperature to freezing, a shift of about 5 c.p.s. occurred. A thermistor was added to the circuit for temperature compensation, and this shift was reduced to 1 c.p.s. over the same temperature change.

Another stage of amplification was added to increase the output signal and provide for cable loading. Tests showed that load changes on this amplifier resulted in frequency shifts. For this reason a buffer stage was added ahead of this last amplification stage to isolate the oscillator from the reflected load changes.

The latest model, which is being readied for sea tests, oscillates at about 6,000 c.p.s. and has a sensitivity of about 130 cycles per degree of temperature. The drift is about one part in 1,000 over an eight-hour period.

Further development is now in progress on a second unit which will include another vibrating wire transducer for pressure measurement in terms of frequency. Also under study is a circuit that will

Encl. (1) to Code 5401-BEO/bah memo of 23 Jul 1958

switch (on demand from the deck) fixed resistors into the device for frequency calibration. This calibration will provide a determination of drift and increase the accuracy of the measurement. No attempt has been made thus far to linearize the output nor has any study been made on utilizing matched thermistors. The unit will be calibrated as a whole and subsequent units also will be calibrated individually.

During the experimental investigation on the circuitry it was found that the circuit was sensitive to a great number of things. For example, the changing battery impedance affected the frequency. This effect was almost entirely eliminated by inserting a 100 mf. capacitor across the battery supply. The locations of individual components and the shape of the finished unit appear to have considerable effect on the stability. Miniature electrolytic capacitors now used in the circuitry no doubt play a part in the drift. It is planned to replace these with either tantalytic or silverlytic types now on order. Since this particular circuit is so frequency-sensitive to changes in level, even transistors must be selected which will give the steadiest performance.

It is planned to have the first unit ready for sea tests next month. The circuit is complete and is awaiting construction of a housing. Bead thermistors in glass probes are on order to be used with this model. Attempts at insulating on-hand thermistors (wafer type) have proven unsatisfactory so far, in that the thermal time constant is increased considerably.

This frequency modulated system, if proven stable and accurate, can be utilized with a variety of other transducers. In this way a certain amount of compatibility in data recording and processing may be realized. The experience gained in this pilot study will be extremely helpful in the future development of frequency sensitive circuits and systems.

Oceanographic Instruments and Systems That Should Be Developed,  
Evaluated, or Further Investigated  
B. E. Olson

A. Requirements

1. Develop a system for measuring and recording properties and movement of water in situ that includes:
  - a. Thermal element
  - b. Depth element (for determining depth of instrument)
  - c. Current sensing element
  - d. Transparency probe
  - e. Conductivity and salinity sensing elements
  - f. Indicating and recording system to be used with the foregoing elements
2. Develop an acoustic device for telemetering information from the foregoing devices to a surface vessel, or to a surface buoy for relay by radio to a vessel or a coastal station.
3. Select the best device available for measuring bottom-pressure fluctuations generated by waves, and investigate the possibility of adapting it to the same system developed for measurements covered by item 1.
4. Investigate the availability of a micro-altimeter suitable for use aboard ship in combination with an accelerometer for obtaining wave measurements while underway.
5. Conduct a full-scale investigation of the accuracy of the bathythermograph and the feasibility of extending measurements to greater depths (2,000 to 3,000 feet). This should include inquiry into whether winches and wire allowances are consistent with depths attainable by the 900-foot BT.
6. Explore in detail the requirements for, and the means of achieving, a geophysical measuring and recording system.
7. Conduct a full-scale evaluation of the Roberts Current Meter, its

Encl. (2) to Code 5401-BEO/bah memo of 23 Jul 1958

accuracy, and the means of simplifying and improving the records it gives. Develop new means of accurately measuring low-velocity currents.

8. Make inquiries of oil-drilling equipment companies, marine instrument designers, and oceanographic institutions as to the best means of insulating and waterproofing cables, cable connections, and instruments under pressure in sea water. (This appears to be a major factor in the reliability of any instrument and warrants separate investigation).

9. Study the various methods for ranging between vessels and buoys over distances of 10 to 4,000 yards.

10. Determine the requirements and potential applications of bottom photography and underwater television.

11. Investigate the availability of portable pyrheliometers and long-wave radiometers.

12. Follow the progress on development of expendable acoustic devices (noise-makers) by NRL.

13. Explore the means of transmitting and converting coded messages directly onto punch cards or other storage media.

14. Explore the desirable configuration and instrumentation of aircraft for oceanographic and other geophysical measurements. (This is a problem of the future but one being approached through the development of the airborne radiation thermometer, radiometers, and wave recorder and through the use of aircraft for magnetic measurements and ice observations.)

#### B. Surfacing Temperature-Depth Probe

The Woods Hole Oceanographic Institution reports that it has designed and used successfully a device that telemeters depth information through water. The advantage of this device is that it eliminates the need for electrical connections with the surface. If this device were combined with a temperature element and other sensing or sampling elements, and a release mechanism, and were made buoyant, the need for any cable connection could be eliminated. The device could be weighted and the release mechanism set to drop the weight at any desired depth. It could then be recovered after surfacing. The advantages of this instrument would be:

- a. No requirement for winch or cable for operation

Encl. (2) to Code 5401-BEO/bah memo of 23 Jul 1958

- b. Elimination of problems related to electrical connections to the surface
- c. Freedom of movement of the vessel during the sounding operation
- d. No restriction on the number of releases that could be made in a given interval of time

Disadvantages and problems of such an instrument would be:

- a. Requirement for deviation by ship from its course to effect recovery unless instrument is inexpensive enough to be expendable.
- b. Difficulty in locating and recovering instrument
- c. Interference from biological noises

#### C. Depth Triggering Device

There seems to be little immediate prospect of obtaining an instrument that will determine salinity in situ to the accuracy required in deep oceanographic work. A possible interim means of speeding up the collection of data now obtained by Nansen bottles and reversing thermometers is a multiple sea sampler precisely triggered by a vibrating wire transducer, or other good depth element. To further speed up this operation, temperature could be sensed continuously by a thermistor and recorded, together with depth, aboard ship.

The major unsolved problem in this system is locating or designing something to trigger the bottles with the precision required. Such a device could be designed either to trigger automatically at the standard depths, or it could be designed for manual triggering from deckside at the discretion of the oceanographer observing the temperature-depth record. For programmed triggering, sensitive tuning forks or circuits might be used; for manual triggering, an electrical or acoustic signal could be transmitted to the device over the cable or through the water.

A simple means that should be investigated for determining the depth of a free-falling device is an impeller such as that used by Hakon Mosby as early as 1942. Such an impeller also might be adapted as a depth triggering device.

## Summary Notes on Hydrographic Office Magnetic, Gravity, and Depth Measurements

### A. Project MAGNET - Airborne Magnetic Surveys (F. B. Woodcock)

The Vector Airborne Magnetometer (VAM) system is one whereby four parameters are measured directly: (1) Direction of the magnetic meridian (magnetic heading, MH), (2) inclination (I) of the magnetic field vector, (3) azimuthal angle of a celestial body (RB), and (4) total intensity of the magnetic field (F). The first three (angular) measurements are made either in, or at right angles to, a "horizontal" plane as defined by a viscous damped pendulum gimballed about the transverse and longitudinal axes of the survey aircraft. The fourth measurement, magnetic intensity, is made with respect to a precisely controlled electric current which is "standardized" by comparison at the USC&GS Magnetic Observatory, Corbin, Virginia. The "standard" current is reproduced on survey operations by correlation with unsaturated standard voltage cells. The data, MH, I, RB, and F, are recorded as functions of time (GMT) accurate to about  $\pm 1$  second.

The VAM measurement of the three angles is accomplished by means of a synchro system wherein the unknown angle,  $x$ , is established in a synchro control transmitter which, in turn, is connected electrically to a remote synchro control transformer. The latter is manually positioned to an angle,  $X$ , which is an integer multiple of  $5^\circ$ . The transformer a.c. output voltage is then determined by  $(x-X)$ , the algebraic sign here indicating the relative phase of the output with respect to the input current to the control transmitter. The indexing mechanism for the control transformer is calibrated to an accuracy of about  $\pm 0.03$  degree for each value of  $(x-X) = 0$  to establish accurate base lines. The residual values,  $(x-X)$  equal to or less than  $5^\circ$ , are detected from the a.c. voltage output and recorded to an accuracy of about  $\pm 0.03$  degree on a recorder which is calibrated to about  $\pm 0.03$  degree. In addition, the recorded data is scaled to an accuracy of about  $\pm 0.03$  degree. Thus, the combined angular error should not exceed about  $\pm 0.12$  degree with respect to the pendulum-established reference system.

The VAM measurement of magnetic intensity is accomplished by passing a precisely controlled electric current through a detector (saturable inductor) which is servo-oriented parallel with the magnetic field vector. The "neutralizing" current is adjusted manually to obtain a value,  $N$ , in precise 50-gamma steps ( $1 \text{ gamma} = 10^{-5} \text{ oersted}$ ), thus establishing a base line. The detector a.c. output voltage is an

Encl. (3) to Code 5401-BEO/bah memo of 23 Jul 1958

amplitude analog of (F-N) = 50 gammas. This is detected and recorded to an accuracy of about  $\pm 3$  gammas and scaled to an accuracy of about  $\pm 1$  gamma. Each base line, N, is established to an accuracy of about  $\pm 20$  gammas. Thus, the overall attainable accuracy of the VAM intensity measurement is about  $\pm 25$  gammas, or better.

The VAM data are combined with Latitude,  $\phi$ , and Longitude,  $\lambda$ , to obtain the following as tabular functions of time:

$$\text{Horizontal intensity} = H = F \cos I$$

$$\text{Vertical intensity} = Z = F \sin I$$

$$\text{Magnetic declination (variation)} = D = TB - MH - RB + L$$

where  $TB$  = True bearing of celestial body

$$= \tan^{-1} \frac{\sin (GHA - \lambda W)}{\cos (GHA - \lambda W) \sin \phi - \cos \phi \tan d}$$

and where  $GHA$  = Greenwich Hour Angle of celestial body

$d$  = declination of celestial body

$L$  = experimentally determined "lubber-line" correction (a constant)

From the above equations, and certain assumptions regarding the earth's magnetic field, it is possible to estimate the error in each computed magnetic element. Thus, the maximum probable error in  $H, \Delta H$ , is about  $\pm 100$  gammas, and in  $Z, \Delta Z$ , is about  $\pm 100$  gammas. The maximum probable error in  $D, \Delta D$ , is about  $\pm 0.25$  degree, excluding errors in  $TB$  due to uncertain  $\phi$  and  $\lambda$ .

The principal deficiency in the system described above lies in the necessity for manual data tabulation, scaling, and reduction of data prior to computation of the results. It is necessary to tabulate as functions of time:  $MH$ ,  $I$ ,  $RB$ ,  $F$ ,  $\phi$ ,  $\lambda$ ,  $GHA$ , and  $d$ , before the Computation Division can reduce the data to punch cards for computation of  $H$ ,  $Z$ , and  $D$ .

The VAM system also allows for recording the aircraft heading with respect to an NI Compass System. This datum is useful for evaluating auto-pilot performance, amount of turning in turbulent air, and so forth.

Aircraft navigation and tracking are accomplished by standard navigational techniques that use the best available data for dead reckoning and position fixing. Data sources include standard flight instruments, the NI Compass System (directional gyro), AN/APN-67 (Doppler radar

Encl. (3) to Code 5401-BEO/bah memo of 23 Jul 1958

navigation system), radio bearings, Loran, search radar, periscopic sextant, driftmeter, and visual observations. Data are combined to determine dead-reckoned positions for selected times. Periodic fixes and lines-of-position are used to correct or modify the dead-reckoned positions. The positions required for tabulation and computation along with magnetometer data are interpolated along the track. The responsibility for execution of navigation and tracking lies with the aircraft operating personnel. Navigational errors, in mid-ocean and under reasonably good flight conditions, should not exceed about five miles. The accuracy of navigation is largely weather-dependent.

An AN/AVN-1 astro-navigational set is being obtained to supplement the navigational periscopic sextant. In addition this unit is being modified to provide RB and thereby supplement or replace the portion of the VAM system devoted to obtaining RB. RB from the AN/AVN-1 modified system will be indicated on a visual mechanical counter and will be recorded periodically along with other navigational data by a 35 mm. data-recording camera.

It is recommended that, as a long range goal, the recording system of the VAM system be modified to eliminate the manual operations. Data ultimately should be recorded directly in a format suitable for direct input to a computer. Reliability, simplicity, and accuracy must, however, be retained or improved if possible. Provided that the AN/AVN-1 astro-navigational set proves successful, data from it also should be recorded for direct computer input.

#### B. Gravity Instruments (A. L. McCahan)

Gravity survey instruments for land surveys are currently accurate to  $\pm 0.1$  milligal. This accuracy is sufficient for all foreseeable geodetic purposes. Ocean survey instruments are currently accurate to  $\pm 3$  milligals. This accuracy is sufficient for present needs but should be improved to  $\pm 1$  milligal for future requirements. Sea gravimeters are currently available for submarine and surface ship use. Inaccuracies in ocean gravity readings obtained by submarines are due primarily to errors in navigation, including effects of subsurface currents. Reports on sea trials of gravimeters are included in Transactions of American Geophysical Union, Vol. 39, No. 3, 1958, and in unpublished Navy reports. With the advent of surface ship gravimeters, new methods for data processing must be adapted to handle the large volume of data which will be obtained.

Encl. (3) to Code 5401-BEO/bah memo of 23 Jul 1958

### C. Depth Recorders (A. L. McCahan)

Commercial depth recorders, as currently manufactured and installed, are adequate for use as navigational aids for performing routine duties. However, these depth recorders have been used in the past for hydrographic survey operations where the degree of accuracy required was higher than that which was obtained.

The basic principle of the depth recorder is the measurement of the time interval between the transmission of the original sound and the reception of the returning echo. The only feature designed into routine depth recorders for time resolution is a synchronous motor which depends upon a constant 60-cycle frequency source. It is readily apparent that a slight frequency variation of one cycle causes a depth recording error of 1.6 percent, or 76.8 feet, at the standard velocity of 4,800 feet per second. Thus, the loss of one cycle while recording depths in 1,000 fathoms produces an error of 16 fathoms and in 2,000 fathoms an error of 32 fathoms.

It is considered that a precision depth recorder (PDR) more adequately satisfies the requirement for detail and accuracy in the recorded sounding than does any of the routine depth recorders. The accuracy of the vertical recording is approximately one part in 3,000 with a time accuracy of one part in a million. However, the precision depth recorder only performs the recording function. The timing precision is made possible by the tuning-fork-controlled, slip-free drive of the facsimile-type recorder. Assuming that one millimeter is the smallest readable unit, the depth as read from the record is accurate to  $\pm 1$  fathom.

The PDR, as presently designed, is considered to be an adequate instrument for recording depth detail with accuracy. The major cause of operative failures is the transmitter used at present with this instrument.

It is recommended that a depth recorder be designed specifically for the purpose of hydrographic surveying. It is further recommended that the better features of such recorders as developed by the oceanographic laboratories be incorporated with those of PDR-type recorders into one precision recorder. Further, it is recommended, where other agencies might be doing developmental work on depth recorders, that the operational personnel of such agencies be consulted concerning the problem.

Encl. (3) to Code 5401-BEO/bah memo of 23 Jul 1958

## Present Status of Hydro Field Instruments

G. Jaffe

A review of the instrumentation questionnaires returned from the survey components of the Hydrographic Office reveals some startling facts. The summary of these comments regarding currently available instruments is attached in tabular form.

Of the fifteen measurements reported on, and the twenty-four instruments used to make these measurements, only two measurements and three instruments are considered adequate for the needs of this Office.

The fact that a major portion of the instrumentation now utilized by the Hydrographic Office in its survey operations is not considered satisfactory by survey personnel leads to the conclusion that the Office is not obtaining a dollar's worth of data for each dollar spent on survey operations. Further, it seems apparent that the best way to increase the value of the data collected is to increase the quality and utility of the instruments used in survey operations.

From the point of view of improving the instruments required for present survey operations, the most effective means will be to define the problem areas (as in enclosure (2) of this report), assign relative priorities to these problems, and provide a development staff in the Instrumentation Division to pursue these problems in the order of their priority and importance to the Hydrographic Office, or provide sufficient funds to accomplish this same development under contract.

By carrying out a well ordered program for the improvement of the instrumentation required for Hydrographic Office survey operations, substantial gains will be made toward increasing the value of the data collected in proportion to the cost of collection.

Encl. (4) to Code 5401-BEO/bah memo of 23 Jul 1958

Table B-1. Summary of Comments from Instrumentation Questionnaires

Measurement	Present Instrument	Accuracy Obtained	Accuracy Required	Yes, or no	Present Instrument Satisfactory? If no, why?
Position	Shoran	Approx. .01%	.01%	No	Uses simple plot sheet, but has limited range
	Lorac	Approx. .01%	.01%	No	Requires specially computed plot sheet
	EPI	.01% .01%	.01%	No	Has poor accuracy
Time	Favag chronograph 60-cycle precision frequency standard	±.02 sec. ±1 sec.	±.02 sec. ±1 sec.	Yes Yes	
Depth of bottom	Edo 255	1% of depth	±1% of depth	No	Has numerous breakdowns
Depth instrument	Telemetric depth recorder Unprotected	±2% ±0.1%	±1%	No	Is erratic
Temperature (ocean)	BT Reversing thermo-meter Resistance thermo-meter	±.5°F ±.02°C ± 0.1°C	±.1°C ±.02°C ±.02°C	No No No	Has poor accuracy Is not continuous, and too delicate Has poor accuracy for deep water

Encl. (4) to Code 5401-BEO/bah memo of 23 July 1958

Table B-1 (cont'd). Summary of Comments from Instrumentation Questionnaires

Measurement	Present Instrument	Accuracy Obtained	Accuracy Required	Present Instrument Satisfactory?	
				Yes, or no	If no, why?
Conductivity	Nansen bottle Conductivity cell	± .04 % <sub>00</sub> ± .02 % <sub>00</sub>	± .02 % <sub>00</sub> ± .02 % <sub>00</sub>	No No	Is not continuous; requires laborious analysis of samples Becomes unstable because of change in cell characteristics
Density	No direct-measuring instrument				
Sound attenuation velocity	No direct-measuring instrument				
Sound attenuation	No direct-measuring instrument				
Ambient noise level	AN/PQM noise measuring set	Unknown	Unknown	Unknown	
Transparency and visibility	Hydrometer Secchi disc	Unknown	Unknown	Unknown	
Water current speed	Roberts meter Ekman meter Price meter	Unknown Unknown Unknown	± 0.1 knot ± 0.1 knot ± 0.1 knot	Partially * No No	Has high threshold level; is maintenance problem Is not continuous or deck-reading Has marginal accuracy; is maintenance problem

\* Modified Roberts meter shows improvement

Table B-1 (cont'd). Summary of Comments from Instrumentation Questionnaires

Measurement	Present Instrument	Accuracy Obtained	Accuracy Required	Present Instrument Satisfactory?	
				Yes, or no	If no, why?
Water current direction	Roberts meter Ekman meter	Unknown Unknown	Unknown Unknown	No No	Same as above Same as above
Tide	Portable tide gage	$\pm 0.1$ foot	$\pm 0.1$ foot	No	Is not bottom mounted, self contained, or unattended
Gravity (ocean)	Submarine gravity meter	$\pm 1$ milli-gal	$\pm 1$ milli-gal	Yes	
Geomagnetism	Vector airborne magneto-meter	$\pm 0.0003$ oersted	$\pm 0.0001$ oersted	Qualified yes	Requires precision lab calibrations; cannot be field checked for calibrations; requires standardization at magnetic observatory; requires precision voltage standards not suited to field use; utilizes some obsolete parts; requires continuous monitoring during flight; uses suspension type galvanometers not suitable for airborne use.



## APPENDIX C. DESCRIPTION OF AN OCEANOGRAPHIC DATA SYSTEM FOR SUBMARINES

Quick Carlson

### A. INTRODUCTION

This specification describes a system incorporating components which already have been tested aboard the USS REDFIN. A prototype of this system underwent sea trials aboard the USS REDFIN in May 1960 and now is operating at the U. S. Navy Hydrographic Office.

The system is completely digital and semiautomatic in operation. Its output is punched paper tape or a digital readout with visual displays of all variables. All outputs are in absolute units and are corrected for various non-linearities and transducer calibration factors. The system utilizes no direct inputs from any system aboard the submarine and, therefore, will require periodic attention for the manual introduction of position data.

### B. REQUIREMENTS

The system has three modes of operation. Each mode is associated with a general submarine maneuver.

#### 1. Mode 1 (Routine)

This mode is for periodic sampling of the environment while the submarine is underway submerged and is shown in Figure C-1. Variables to be recorded include: (1) Time, (2) day of the year, (3) octant of the globe, (4) latitude, (5) longitude, (6) depth of the submarine, (7) sound velocity, and (8) sea temperature.

#### 2. Mode 2 (Diving)

This mode will be switched on before vertical dives. The variables to be recorded are the same as those in Mode 1 except that speed and ambient light level are recorded instead of position. These variables are shown in Figure C-2 and include: (1) Time, (2) day of the year, (3) speed, (4) ambient light, (5) depth of the submarine, (6) sound velocity, and (7) sea temperature.

#### 3. Mode 3 (Hovering)

This mode is shown in Figure C-3 and will be used to obtain

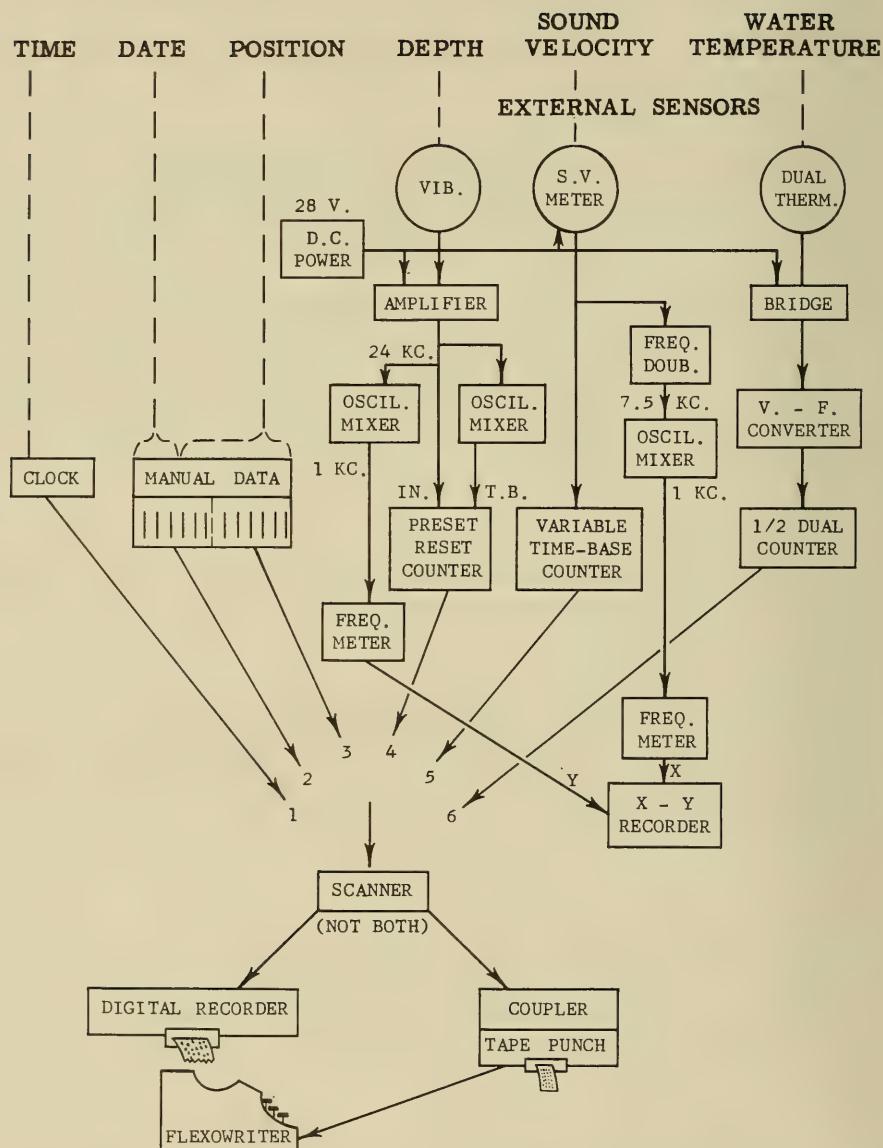


Figure C-1. Mode 1 (Routine) for Digital Oceanographic Data System

wave height and roll angle data primarily when the submarine is hovering. The variables to be recorded are (1) wave height and (2) roll. The repetition rate is less than 0.6 second.

## C. DESCRIPTION OF SYSTEM

### 1. System components

The system consists of sensors for measuring the appropriate variables, digitizing components to convert sensor outputs to digital form where required, displays for all recorded information, a scanner to feed the information alternately from each sensor to the recorder or tape punch, a digital recorder for optional use in lieu of the tape punch, a tape punch to make a permanent record of the recorded variables and allow a direct input to the Hydrographic Office digital computer (Burroughs 205), and a Flexowriter to annotate the punched tape further, as necessary, and to play back the punched data in the field for its verification. The proposed oceanographic console is shown in Figure C-4.

### 2. Sensors

With the exception of the clock, calendar, and manual inputs, all sensors are mounted in a single transducer housing as shown in Figure C-5. This housing requires a single foundation and may be mounted either on the deck or atop the sail. A single multiconductor cable from the transducer housing to the recorder console requires only one pressure hull penetration. All other inputs, such as time, date, position, etc., originate in the oceanographic console itself.

Pressure (depth) is sensed by a vibrating wire transducer in the sensor housing. Its output is a frequency which is inversely proportional to depth. This instrument has undergone repeated tests aboard the USS REDFIN without a single failure.

Sound velocity is obtained from a Bureau of Standards velocimeter located in the sensor housing. This instrument was found to be quite reliable during shipboard operations. The output of this transducer is a frequency which is directly proportional to sound velocity in feet per second.

The temperature probe consists of dual thermister elements. The output of the bridge is a voltage which is directly proportional to temperature. The thermisters have been tested both in the laboratory and aboard the USS REDFIN and yield accuracies of about  $\pm 0.1^{\circ}\text{C}$ .

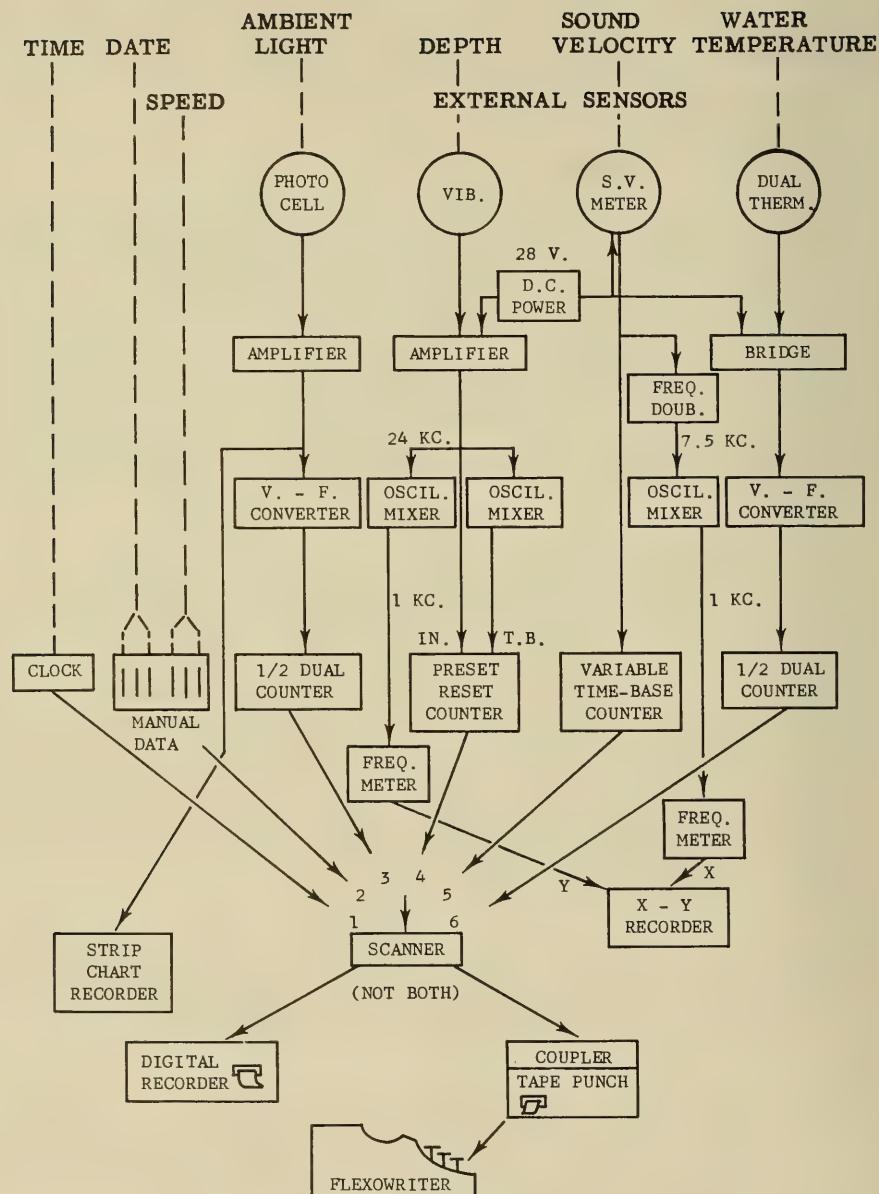


Figure C-2. Mode 2 (Diving) for Digital Oceanographic Data System

Ambient light measurements are obtained from a single photocell located in the transducer housing. Its output is amplified and modulated in the same manner as the temperature subsystem.

Wave heights are recorded from an Edo 255B transducer mounted in the transducer housing. The distance to the surface is recorded approximately every 0.6 second or less. Roll angle is recorded simultaneously with the wave data. When the submarine is hovering, these data are adequate to allow spectral analysis of the wave heights.

### 3. Recorders

The scanner is a six-digit, six-channel stepping switch which allows the digitized outputs of each sensor to pass in sequence to the digital recorder or the tape punch coupler. Each channel is identified by an indicator number at the left of each channel output.

The digital recorder is operated by the scanner and provides a printed record similar to a cash register receipt of all variables sampled by the scanner.

The paper tape punch is connected to the scanner by means of the coupler. The function of the coupler is to convert the parallel data from the scanner to the serial form required by the tape punch. The tape punch and coupler operate directly from the scanner and cannot be used at the same time as the digital recorder. The punched tape format is compatible with the Burroughs 205 computer and the Flexowriter.

The Flexowriter is an off-line component of the system and is used for annotating the rolls of punched tape as to year, ship, and other identifiers. It likewise will be used to reproduce punched tape data for operational use by the ship personnel and for verification of the correct operation of the tape punch unit.

### 4. Procedures

Outputs from the clock, calendar, and manual inputs are in digital form and require no further digitizing.

Depth and sound velocity signals, being in frequency form, are digitized by variable time-base counters. Temperature and ambient light signals are converted to frequency by a voltage-to-frequency converter and then digitized by an electronic counter.

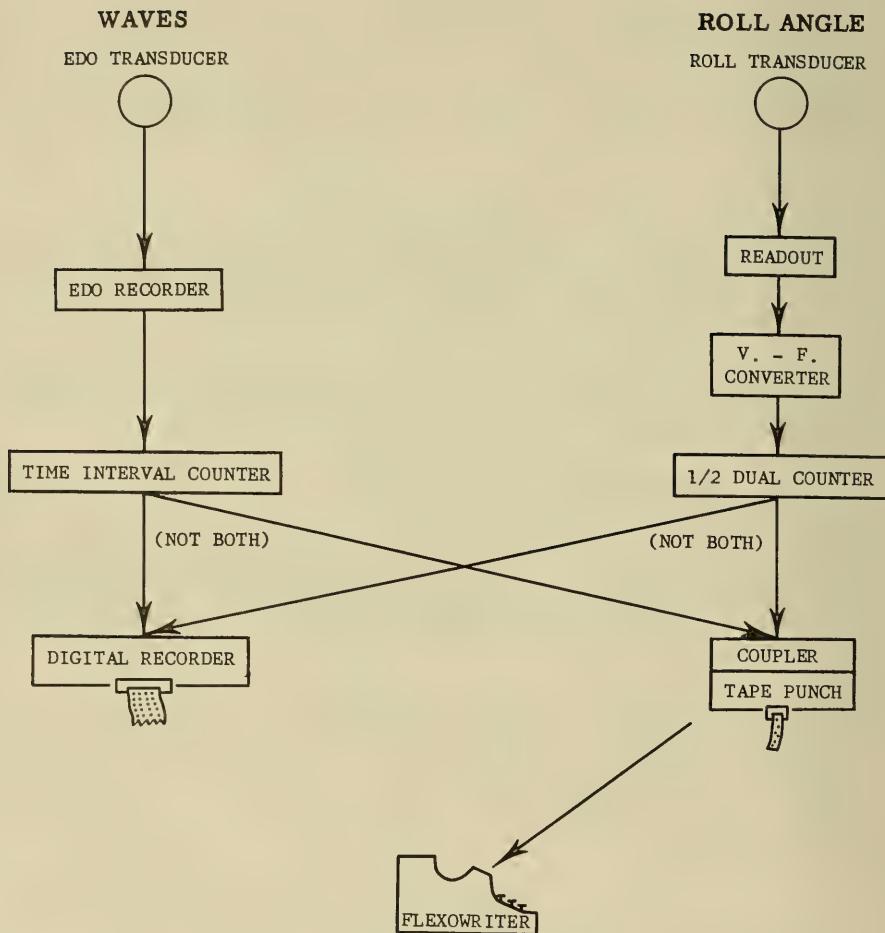


Figure C-3. Mode 3 (Hovering) for Digital Oceanographic Data System

The outgoing and return pulses of the echo sounder gate a 25-kilocycle signal on an electronic counter, resulting in digitized values of distance to the surface directly in feet and tenths.

## 5. Data format

### a. Mode 1 (Routine)

The complete data message, which may be recycled as often as every two seconds, consists of 36 digits of data and six channel identifiers. While the format may be changed to a prearranged set of rules, the following example is a typical data message as would be received from the digital recorder.

```
6 0 0 2 3 3 5
5 0 0 4 9 7 1
4 0 0 2 2 4 3
3 5 0 7 6 5 5
2 1 3 0 0 3 8
1 1 1 1 8 2 7
```

The first vertical column represents the channel indicator. Channel 1 is GMT time: 11 hours 18 minutes 27 seconds. The first three digits of Channel 2 indicate the day of the year: the 130th day is 9 May; the next digit is the octant of the globe: Octant 0 for 0° to 90°W. north latitude as in the World Meteorological Organization code; and the last two digits are degrees of latitude: 38°. The first two digits of Channel 3 are minutes of latitude: 50'; these are followed by degrees and minutes of longitude: 76°55'. Channel 4 shows the depth of the submarine in feet and tenths: 224.3 feet. Channel 5 indicates the sound velocity in feet per second: 4,971 feet per second. Channel 6 is the sea temperature in degrees and hundredths Centigrade: 23.35°C. The sign of the observation is given by the first digit following the channel indicator: 0 = positive, 1 = negative.

### b. Mode 2 (Diving)

The complete data message is similar to that from Mode 1.

```
6 0 0 2 3 3 5
5 0 0 4 9 7 1
4 0 0 2 2 4 3
3 0 0 0 5 2 5
2 1 3 0 0 3 5
1 1 1 1 8 2 7
```

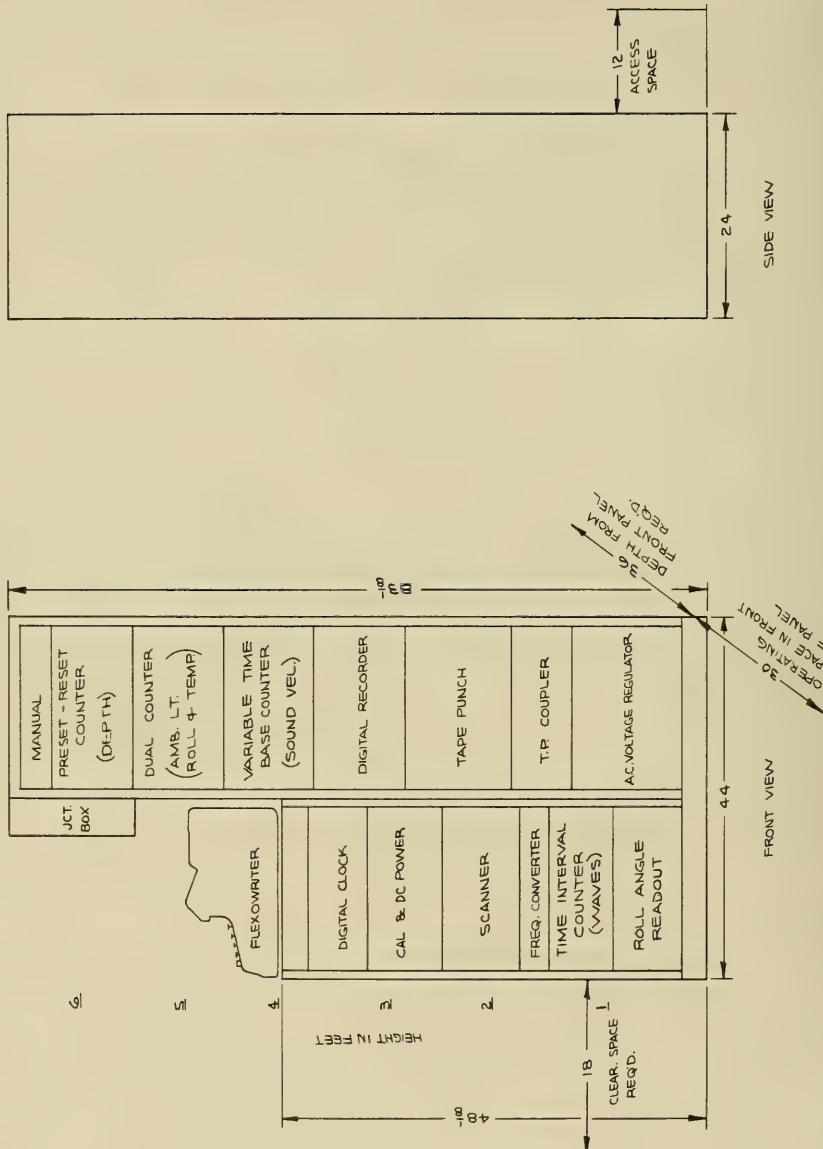


Figure C-4. Submarine Oceanographic Data Console

The exceptions are found in Channels 2 and 3. The first three digits of Channel 2 are still the day of the year; however, the last three digits are now speed in knots and tenths: 3.5 knots. Channel 3 now indicates the ambient light in lumens: 525 lumens. All other channels record the same data as in Mode 1.

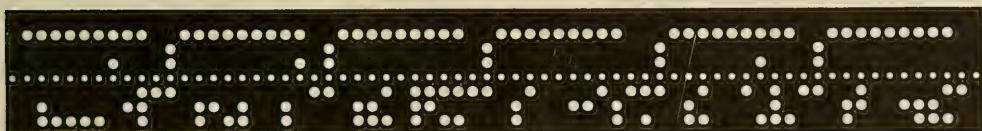
### c. Mode 3

In this mode the scanner is not used because of its slow repetition rate. Wave height and roll angle signals go directly from the counters into the digital recorder or the tape punch. The message appears as a single line of data that is repeated every 0.6 second.

```
6 8 1 1 0 1 2
6 8 5 0 0 0 4
6 9 0 0 0 1 5
```

The first three digits of each line indicate the distance to the surface in feet and tenths: 69.0 feet, 68.5 feet, and 68.1 feet. The fourth digit shows the direction of roll: 0 = port, 1 = starboard. The last three digits show the roll angle in degrees and tenths:  $1.5^\circ$  to port,  $0.4^\circ$  to port, and  $1.2^\circ$  to starboard.

An example of punched tape containing the same information as the message for Mode 1 is shown below. Here, each channel (data word) is prefixed by two digits to indicate the data format; format 03 is shown. Each data word is separated by a tab and a space. The tab allows columnated reproduction on the Flexowriter, and the space is a requirement by the computer for separating data words.



An x-y recorder may be incorporated, as shown in Figures C-1 and C-2, to record the variation in certain events during a change in depth. Likewise, a strip chart recorder may be used to record the variation of an event like ambient light with time.

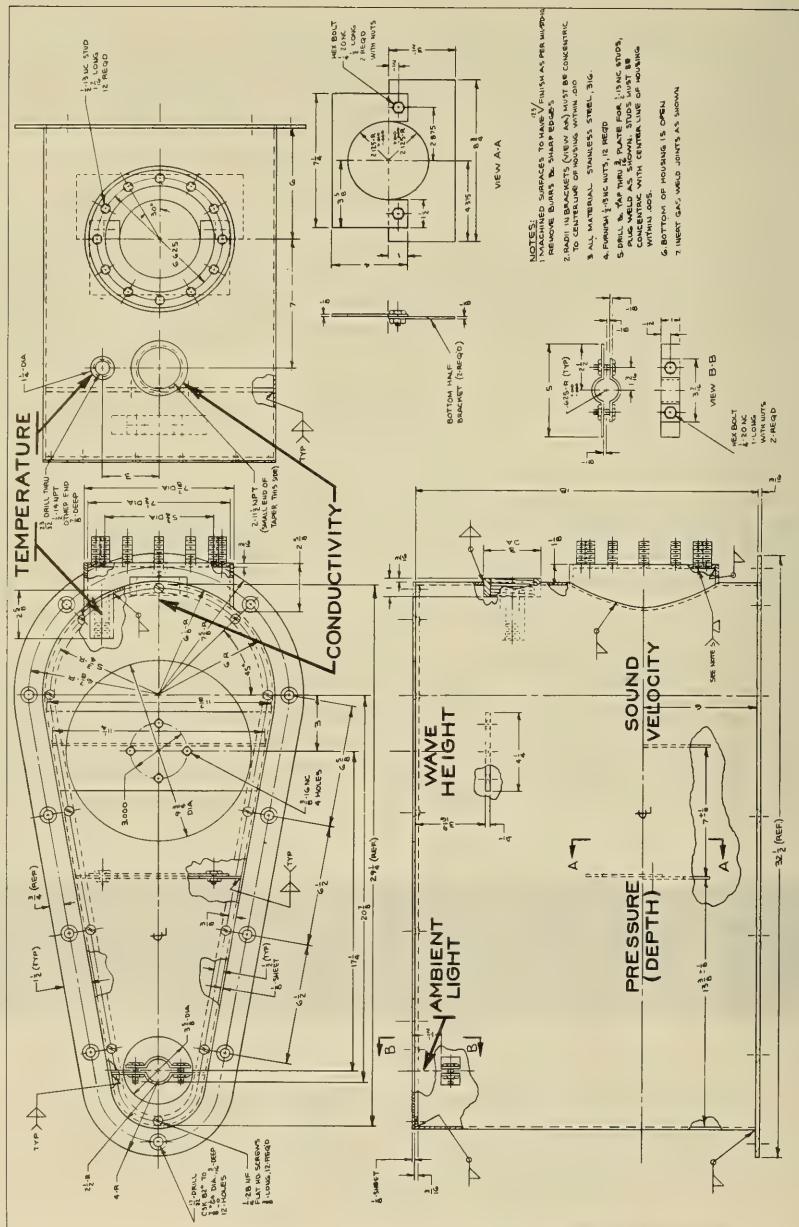


Figure C-5. Housing for Sensing Elements for Digital Oceanographic Data System

## D. INSTALLATION

### 1. Cost of equipment and installation

The total cost of the equipment components is approximately \$40,000 plus an estimated \$10,000 for shipyard installation costs. The components are not built to military specifications and are essentially stock items. Delivery of all components requires three to four months.

### 2. Power and space

The power required for the system is single phase 115-volt a.c., 33-amp sustained load.

The space required for the equipment is 44 inches wide, 24 inches deep, and 83 1/8 inches high. An access space of 12 inches is required behind the console plus 18 inches at one end. Approximately 30 inches is required in front of the console for the operator.

### 3. Operation of the equipment

The equipment operations do not require the constant attention of a professional oceanographer. Data are to be collected according to prearranged schedules, and tapes will be forwarded to the Hydrographic Office for analysis.

### 4. Data reduction

The final form of the data will be a number of rolls of perforated tape. This tape will be compatible with the Burroughs 205 computer. Data reductions will be automatic by the computer. Computer outputs will consist of spectra for the wave data and automatic cataloging and filing of temperatures and sound velocities according to depth, time, and position for further subsequent analysis.



## APPENDIX D. CONTINUOUS-PROFILE EQUIPMENT FOR OBTAINING SUBBOTTOM REFLECTIONS

Adrian F. Richards

Contained in this appendix is a tabulation of the details of and notes on various continuous-profile sound source systems used for obtaining subbottom reflections and, thus, delineations of the subbottom structure. Included are an evaluation and recommendation for each instrument system (Item 17) and one or more reference sources from which the details were obtained (Item 18). Following the detailed tabulation is a summary (Table D-1) which enables a rapid comparison of Items 4 through 13 between one system and any other. Also included in this table is the statement as to whether or not a particular system has been used for routine surveys. The continuous-profile systems covered in this appendix are (A) Substrata Acoustic Probe (Marine Sonoprobe); (B) "Smith-Cummings-Meichner Apparatus"; (C) Subbottom Depth Recorder (SDR); (D) Seismic Profiler; (E) Subsurex (Subsurface Explorer); (F) Marine Seismic System; and (G) Sonar Thumper. The references cited for these systems are listed in Part E of Section X. Table D-1 also includes some data on an AN/UQN-PDR System which is mentioned in References X-6 and X-36.

### A. SUBSTRATA ACOUSTIC PROBE (MARINE SONOPROBE)

Marine Sonoprobe is the trade mark of the Magnolia Petroleum Company. This instrument was designed for resolution of thin beds (one to two feet thick). A later model is used by the Naval Electronics Laboratory (NEL).

1. Model: 401 (USNHO)
2. Manufacturer: Scientific Service Laboratories, Inc., Dallas, Texas
3. Approximate cost new: \$19,412 (1956)
4. Maximum water depth in which operative:  
Empirically determined: 700 feet (NEL)  
Estimated: 700 feet
5. Maximum penetration of sediment:  
Empirically determined: 50 feet (NEL), 200 feet (Magnolia;  
record not published)  
Estimated: 200 feet

A. SUBSTRATA ACOUSTIC PROBE (MARINE SONOPROBE) (cont'd)

6. Transducers:

Type: Transmitter: magnetostrictive; Receiver: barium titanate

Location: Hull-mounted (USNHO, NEL) or outboard (Magnolia)

7. Acoustic power: 1.2 to  $1.5 \times 10^5$  watts (estimated), assuming an electrical to acoustic conversion efficiency of 25 percent to 30 percent. (The acoustic power of the NEL Sonoprobe was measured to be  $10^4$  watts, which the manufacturer believes to be below normal: D. G. Moore, written communication.)

8. Acoustic frequency:

Approximate range: 1.5 to 9.8 kilocycles

Peak: 3.8 kilocycles

9. Acoustic pulse length: 0.3 millisecond

10. Acoustic pulse repetition rate: 12 pulses per second

11. Receiver band pass filter network: Adjustable

High pass: 1.1 kilocycles

Low pass: 9.8 kilocycles

12. Graphic record:

Scale: 0 to 100 and 100 to 200 feet (USNHO); 0 to 200 and 200 to 400 feet (NEL and Magnolia)

Paper type: Dry, electrosensitive (Teledeltos L-48)

Paper dynamic range: About 2.5 db

13. Net weight: 687 pounds

14. Relay rack (19 inches wide) panel space: 65 inches

15. A. C. power consumption: 1,500 watts

16. Evaluation and recommendations:

- a. Equipment has been used successfully for routine surveys.
- b. Equipment provides high resolution but low penetration.
- c. Equipment is recommended for high resolution studies in shallow water where deep penetration is unnecessary.

17. References: X-18, -19, -20, -23, and -24

## B. "SMITH-CUMMINGS-MEICHNER APPARATUS"

1. Model: No model number; designed by W. O. Smith, G. B. Cummings, and F. Meichner
2. Manufacturer: Target Rock Corp., Hempstead, N. Y.; Telephonics Corp., Huntington, N. Y.
3. Approximate cost new: \$15,000 to \$18,000 (March 1959)
4. Maximum water depth in which operative:  
Empirically determined: 100 feet  
Estimated: 250 feet
5. Maximum penetration of sediment:  
Empirically determined: 800 feet (with transducer placed on the bottom; 200 to 300 feet (with transducer at the surface))  
Estimated: 1,500 feet
6. Transducers:  
Type: Transducer-receiver: ammonium dihydrogen phosphate (ADP) crystals  
Location: Outboard, fixed to side of ship. (A later model uses transducers mounted on a sled that is towed along the bottom: W. O. Smith, personal communication.)
7. Acoustic power: 250 to 2,500 watts
8. Acoustic frequency:  
Approximate range: Apparatus is designed for operation only at certain peak frequencies.  
Peak: 6, 11.5, and 16 kilocycles. (The transducer has a natural resonance of 11 kilocycles. At 6 kilocycles, the output power is 10 db below that of the normal 11-kilo-cycle operation.)
9. Acoustic pulse length: 1, 2, 3, 5, 7, or 9 milliseconds
10. Acoustic pulse repetition rate: 250 pulses per second
11. Receiver band pass filter network: None

B. "SMITH-CUMMINGS-MEICHNER APPARATUS" (cont'd)

12. Graphic record:

Scale: 0 to 70, 140, and 420 meters  
Paper type: Chemically treated  
Paper dynamic range: About 20 db

13. Net weight: 500 pounds

14. Relay rack (19 inches wide) panel space: 96 inches or less

15. A.C. power consumption: About 200 watts

16. Evaluation and recommendations:

- a. Equipment has been used for routine surveys
- b. Equipment is capable of either high resolution or moderate penetration with the selection of suitable frequencies

17. References: X-33

C. SUBBOTTOM DEPTH RECORDER (SDR)

The Subbottom Depth Recorder was developed by staff members of the Lamont Geological Observatory.

1. Model: No model number; designed by B. Luskin, A. C. Roberts, and W. C. Beckman

2. Manufacturer: Alpine Geophysical Associates, Norwood, N. J.

3. Approximate cost new: \$18,975 (May 1959), including sparker, (electrical spark source), RASS (repeatable acoustic seismic source), and shipment-storage cases. Price does not include accessory recorder.

4. Maximum water depth in which operative:

Empirically determined: About 2,400 feet  
Estimated: Not known

5. Maximum penetration of sediment:

Empirically determined: 1,500 feet  
Estimated: Greater than 2,000 feet

## C. SUBBOTTOM DEPTH RECORDER (SDR) (cont'd)

### 6. Transducers:

Type: Transmitter: sparker, or RASS (which uses liquid propane at a rate of one pound per hour and oxygen at a rate of 30 cubic feet per hour with an approximate volumetric ratio of 1:5, respectively); Receiver: hydrophone

Location: Hull-mounted, or towed astern (recommended)  
Transmitter life: Sparker: 4 hours (average); RASS: 30 hours (average)

### 7. Acoustic power:

Sparker:  $10^5$  watts (estimated); RASS:  $10^7$  watts (estimated)

### 8. Acoustic frequency:

Approximate range: Sparker: 30 c.p.s. to 5 kilocycles; RASS: 30 c.p.s. to 3 kilocycles

Peak: Sparker: 60 to 150 c.p.s.; RASS: 35 c.p.s.

### 9. Acoustic pulse length: Sparker: 4 to 10 milliseconds; RASS: 6 to 15 milliseconds

### 10. Acoustic pulse repetition rate: Sparker: 1, 2, 3, or 4 pulses per second; RASS: 1 or 2 pulses per second

### 11. Receiver band pass filter network: Adjustable

High pass: 7 c.p.s.

Low pass: 7 kilocycles

### 12. Graphic record:

Scale: 0 to 600, 800, 1,200, and 2,400 feet

Paper type: Dry, electrosensitive (Teledeltos NDA), when used with the Precision Depth Recorder

Paper dynamic range: About 10 db

Precision of time base: 3 parts in 1 million

### 13. Shipping weight: About 2,500 pounds (including recorder)

### 14. Relay rack (19 inches wide) panel space: About 80 inches (2 racks; may not include power supply)

### 15. A.C. power consumption: Sparker: 3 kilowatts; RASS: 1 kilowatt

## C. SUBBOTTOM DEPTH RECORDER (SDR) (cont'd)

### 16. Evaluation and recommendations:

- a. Equipment has been used by Lamont Geological Observatory and Alpine Geophysical Associates for routine surveys.
- b. Equipment is capable of either high resolution or relatively deep penetration with the selection of suitable frequencies.
- c. The speed of sound in sediments can be measured by using this equipment with a wide separation of the transmitter and receiver.
- d. The SDR is used with a PDR or PGR
- e. The use of a PGR with the SDR is preferable to using a PDR.

### 17. References: X-1 and X-2

## D. SEISMIC PROFILER

Patents on the equipment and method used by the Seismic Profiler have been applied for by the Woods Hole Oceanographic Institution (WHOI).

1. Model: No model number; designed by S. T. Knott

2. Manufacturer: Woods Hole Oceanographic Institution, Woods Hole, Mass.

3. Approximate cost new: \$6,000, not including the PGR

4. Maximum water depth in which operative:

Empirically determined: 15,800 feet with all ship noise stopped; 2,400 feet with ship moving at 6 knots (S. T. Knott, written communication)

Estimated: Not known

5. Maximum penetration of sediment:

Empirically determined: 1,200 feet (600 feet of penetration is a more practical value when the instrument is used in water 50 to 60 feet deep: S. T. Knott, written communication)

Estimated: Not known

## D. SEISMIC PROFILER (cont'd)

### 6. Transducers:

Type: Transmitter: Sparker; Receiver: wideband omnidirectional, or at times directional, hydrophone

Location: Both transducers are towed 10 to 20 feet apart aft of the ship at a depth of 3 to 5 feet and a speed of 4 to 6 knots. The transducers can be hull-mounted if the ship is sufficiently quiet.

Transmitter life: About 7 hours

7. Acoustic power: Sparker:  $1.3 \times 10^3$  watts (calculated from a measured value of 100 db above a microbar)

### 8. Acoustic frequency:

Approximate range: 30 c.p.s. to 10 kilocycles

Peak: 300 to 600 c.p.s.

9. Acoustic pulse length: 0.1 to 0.2 millisecond. (A bubble pulse of about 4 milliseconds is associated with the discharge pulse.)

10. Acoustic pulse repetition rate: 2 to 4 pulses per second (normal), 20 pulses per second (maximum)

11. Receiver band pass filter network: Adjustable

High pass: 75 c.p.s.

Low pass: 10 kilocycles

12. Graphic record:

Scale: 0 to 20, 40, 50, 100, 150, 200, 300, 400, 500, 1,000, 1,500, and 3,000 fathoms

Paper type: Wet, electrosensitive (Alfax A)

Paper dynamic range: About 20 db

13. Net weight: About 1,000 pounds (excluding recorder)

14. Relay rack (19 inches wide) panel space: 120 inches (one 72-inch panel and one 48-inch panel)

15. A.C. power consumption: Not known, except that a 5-kilovolt-ampere source is sufficient

#### D. SEISMIC PROFILER (cont'd)

##### 16. Evaluation and recommendations:

- a. Equipment has been used for routine surveys in bays and on the Continental Shelf. Deep-sea work has been experimental.
- b. Equipment is capable of either very high resolution or relatively deep penetration with the selection of suitable frequencies, recorder scale, and writing rate.
- c. The speed of sound in sediments can be measured by using this equipment with a wide separation of the transmitting and receiving transducers.
- d. Equipment is used at WHOI with a 1- to 4- (usually 2-) channel PGR. The flexibility of the PGR, or simplified PGR, appears to make the Seismic Profiler (with spark source) more versatile than the SDR (with spark source). However, no quantitative information is known to exist on the actual comparative capabilities of the Seismic Profiler and the SDR when operated in the same area under controlled conditions.

##### 17. References: X-7 and X-12

#### E. SUBSUREX (SUBSURFACE EXPLORER)

The Subsurex equipment and system is protected by U. S. Patent No. 2,866,512. The U. S. Government has a royalty-free license covering use of the equipment for governmental purposes. Patent protection for certain system components has been applied for. A second experimental model is being constructed privately by Mr. Padberg (written communication).

1. Model: No model number; experimental, designed by L. R. Padberg, Jr.
2. Manufacturer: NEL
3. Approximate cost new: \$100,000 (probably includes development cost)
4. Maximum water depth in which operative:  
Empirically determined: 3,000 feet  
Estimated: Greatest known depths (L. R. Padberg, Jr., written communication)

## E. SUBSUREX (SUBSURFACE EXPLORER) (cont'd)

5. Maximum penetration of sediment:  
Empirically determined: 1,500 feet  
Estimated: Several thousand feet
6. Transducers:  
Type: Transmitter: magnetostrictive; Receiver: crystal  
Location: Outboard
7. Acoustic power: About  $5 \times 10^5$  watts (calculated from a measured value of 137.5 db/dyne/cm<sup>2</sup> at 1 meter)
8. Acoustic frequency:  
Approximate range: 0.1 to about 14 kilocycles  
Peak: 10 and 14 kilocycles
9. Acoustic pulse length: 0.1 to 10 milliseconds
10. Acoustic pulse repetition rate: Variable (1 pulse per second in the literature)
11. Receiver band pass filter network: Adjustable  
High pass: 20 c.p.s.  
Low pass: 20 kilocycles
12. Graphic record:  
Scale: 0 to 1,000, 9,000, 15,000, and 45,000 feet  
Paper type: Chemically treated  
Paper dynamic range: Probably about 20 db
13. Net weight: 1,600 pounds
14. Relay rack (19 inches wide) panel space: 120 inches (two 60-inch panels)
15. A.C. power consumption: 5 kilovolt-amperes
16. Evaluation and recommendations:
  - a. Equipment has not been used for routine surveys.
  - b. Sediment penetration statements may be liberal.
17. References: X-26

## F. MARINE SEISMIC SYSTEM

1. Model: Not known
2. Manufacturer: Socony Mobil Oil Co., Inc., Dallas, Texas
3. Approximate cost new: Not known
4. Maximum water depth in which operative:  
Empirically determined: 140 feet  
Estimated: 1,000 feet or more
5. Maximum penetration of sediment:  
Empirically determined: 8,000 feet (for sand and shale)  
Estimated: Possibly greater than 8,000 feet for other sediments
6. Transducers:  
Type: Transmitter: gas gun (which uses liquid propane at a rate of 12 gallons per hour, oxygen at 300 standard cubic feet per hour, and air at 10,000 standard cubic feet per hour); Receiver: ADP crystals  
Location: Transmitter: outboard; Receiver: 20 receivers in a string 150 feet long towed 450 feet astern of the transmitter.
7. Acoustic power: About 6,500 watts (in water)
8. Acoustic frequency:  
Approximate range: 5 to 400 c.p.s.  
Peak: 50 c.p.s.
9. Acoustic pulse length: 10 milliseconds
10. Acoustic pulse repetition rate: 20 pulses per minute
11. Receiver band pass filter network: Adjustable  
High pass: 25 to 284 c.p.s.  
Low pass: 9 to 200 c.p.s.
12. Graphic record:  
The recorder utilizes a magnetic drum compositor on which the signal is mixed and composited before being recorded.  
Scale: 3 seconds of time are equivalent to 18 inches of paper.  
Paper type: Wet, electro-sensitive (Alfax A)  
Paper dynamic range: 20 db

## F. MARINE SEISMIC SYSTEM (cont'd)

13. Net weight: Transmitter: 250 pounds; Electronics: 1,000 pounds
14. Relay rack (19 inches wide) panel space: two 72-inch racks
15. A. C. power consumption: 1,000 watts

### 16. Evaluation and recommendations:

Since this equipment has been in operation for only a few months, its performance has not yet been evaluated.

## 17. References: X-21

## G. SONAR THUMPER

1. Model: ST-8, 400 watt-seconds, designed for surface operation.  
(Models that are expected to have outputs of 1,200 and 5,000 watt-seconds are under development.)
2. Manufacturer: Edgerton, Germeshausen & Grier, Inc., Boston, Mass.
3. Approximate cost new: \$3,500 (1960), for Thumper alone
4. Maximum water depth in which operative:  
Empirically determined: 1,800 feet  
Estimated: Not known
5. Maximum penetration of sediment:  
Empirically determined: 300 feet  
Estimated: Not known, but probably greater than that of the Seismic Profiler
6. Transducers:  
Type: Transmitter: Thumper ("The actual transducer consists of an aluminum disk 16 inches in diameter which rests against the face of a flat coil. When a large capacitor bank is discharged through the coil, the eddy currents induced in the disk force the disk away from the coil so as to produce a large pressure pulse." Hayward in Reference X-7); Receiver: Barium titanate  
Location: Transmitter: generally towed; Receiver: optimum location not known yet

G. SONAR THUMPER (cont'd)

7. Acoustic power:  $1.3 \times 10^4$  watts
8. Acoustic frequency:
  - Approximate range: 200 c.p.s. to several kilocycles
  - Peak: 1.4 kilocycles
9. Acoustic pulse length: 0.5 millisecond
10. Acoustic pulse repetition rate: 1/2, 1, 3, or 5 seconds per pulse
11. Receiver band pass filter network: Adjustable
  - High pass: 75 c.p.s.
  - Low pass: 10 kilocycles
12. Graphic record:
  - Scale: 0 to 20, 40, 50, 100, 150, 200, 300, 400, 500, 1,000, 1,500, and 3,000 fathoms
  - Paper type: Wet, electrosensitive (Alfax A)
  - Paper dynamic range: About 20 db
13. Net weight: 335 pounds (only Thumper and capacitors)
14. Relay rack (19 inches wide) panel space: Not known
15. A. C. power consumption: 2 kilowatts
16. Evaluation and recommendations:
  - Since this equipment has been in operation for only a few months, its performance has not yet been evaluated.
17. References: X-7

Item	Part Feature	Part Name	A	B	C	D	E	F	G	H
4	Water depth, empirical max.	Marine Sonoprobe	"S-M-C Apparatus"	Subbottom Depth Recorder	Seismic Profiler	Subsurrex	Marine Seismic System	Sonar	AN/UQN-PDR	
5	Sed. penetration, empirical max.	200'	100'	2,400'	15,800'	3,000'	140'	1,800'	About 18,000', 120'	
6	Transducer type, transmitter	ADP crystals	Sparker or RASS	Sparker	Magneto-strictive	Gas gun	Thumper	ADP crystals		
7	Acoustic power, watts*	1.5 x 10 <sup>5</sup>	0.25 to 2.5 x 10 <sup>3</sup>	Sparker: 10 <sup>5</sup> (est.) RASS: 10 <sup>7</sup> (est.)	1.3 x 10 <sup>3</sup>	5 x 10 <sup>5</sup>	6.5 x 10 <sup>3</sup>	1.3 x 10 <sup>4</sup>	300	
8	Acoustic frequency	1.5 to 9.8 kc	6, 11.5, 16 kc	Sparker: 0.3 to 5 kc RASS: .03 to 3 kc	.03 to 10 kc	0.1 to 14 kc	5 to 400 c.p.s.	200 to several thousand c.p.s.	12 kc	
9	Pulse length, milliseconds	0.3	1, 2, 3, 5, 7, 9	Sparker: 4 to 10 RASS: 6 to 15	0.1 to 0.2**	0.1 to 10	10	0.5	3 to 5	
10	Pulse repetition, rate per second	1.2	250	Sparker: 1, 2, 3, 4 RASS: 1, 2	2 to 4 (normal), 20 (max.)	1	20 / minute	12, 20, 60, 120 minute	1	
11	Filter network	yes	no	yes	yes	yes	yes	yes	no	
12	Recorder type	Special	Special	PDR	PGR	Special	Special	PGR	PDR	
13	Net weight, pounds	687	500	2,500 (shipping weight)	About 1,000 (excluding recorder)	1,606	1,250	About 335 (Thumper and capacitors only)	740	
--	Used for routine surveys	yes	yes	yes	yes	no	not known	not known	yes	

\* In comparison, the energy of a one-pound spherical charge of TNT equals about 10<sup>11</sup> watts, and the energy of an Engineer's Special dynamite cap about 10<sup>7</sup> watts.

\*\* Associated bubble pulse length is 4 milliseconds.

Table D-1. Summary and Comparison of Features of Continuous-Profile Equipment



## APPENDIX E. INSTRUMENTATION SUMMARY

The summary presented in this Appendix was prepared to show the instrumentation trend both at the Hydrographic Office and, insofar as is known, at other government and private activities. It is recognized that this summary is not all inclusive of the instrumentation in the fields of oceanography and marine geophysics; some of the instruments and systems mentioned here are not included in the main part of the Committee report, and vice versa. The instruments listed in the column headed "present method" are generally those currently in use at the Hydrographic Office although most of them were developed by others.

## U. S. NAVY HYDROGRAPHIC

MEASUREMENT	PRESENT METHOD	OPERATING LIMITS	TYPE OF RECORDING	METHODS IN DEVELOPMENT	OPERATING LIMITS	TYPE OF RECORDING
TEMPERATURE	Mechanical Bathymeterograph Deep-Sea Reversing Thermometers Wire-Wound Resistance Thermometer Airborne Radiation Thermometer Thermocouples	DEPTH: 0 to 900 feet Accuracy: $\pm 10$ feet TEMPERATURE: -2 to 32°C Accuracy: $\pm 0.1^\circ\text{C}$  DEPTH: 0 to 20,000 feet Accuracy: $\pm 100$ feet TEMPERATURE: -2 to 30°C Accuracy: $\pm 0.01^\circ\text{C}$  DEPTH: Surface TEMPERATURE: -5 to 30°C -25 to 50°C Accuracy: $\pm 0.1^\circ\text{C}$  DEPTH: 0 to 200 feet TEMPERATURE: -50 to 10°C Accuracy: $\pm 0.5^\circ\text{C}$	Temperature versus depth information scribed on metallic coated glass slide  Visually observing and manually recording from numbered scale on thermometer  Temperature versus time on strip paper chart  Temperature versus time on strip paper chart	Electronic Linear Bathymeterograph High Speed Towed Bathymeterograph Shipboard Thermocline Recorder Thermistor Chain Thermal Tow (Sea-Surface Temperature) Submerged Buoy Thermocline Recorder	DEPTH: 0 to 1,500 feet Accuracy: $\pm 6$ feet TEMPERATURE: 0 to 30°C Accuracy: $\pm 0.01^\circ\text{C}$  TOED SPEEDS: 0 to 25 knots DEPTH: 0 to 1,000 feet Accuracy: $\pm 10$ feet TEMPERATURE: 0 to 30°C Accuracy: $\pm 0.01^\circ\text{C}$  DEPTH: 0 to 1,000 feet TEMPERATURE: 0 to 30°C Accuracy: $\pm 0.01^\circ\text{C}$  DEPTH: 0 to 200 feet; predetermined depth points TEMPERATURE: 0 to 30°C Accuracy: $\pm 0.02^\circ\text{C}$  TEMPERATURE: -5 to 30°C Accuracy: $\pm 0.1^\circ\text{C}$  DEPTH: 0 to 300 feet TEMPERATURE: 0 to 30°C Accuracy: $\pm 0.01^\circ\text{C}$	A) X-Y Chart B) Capabilities for: 1. Magnetic tape 2. Punched paper tape 3. Direct temperature observation on electronic counter  A) X-Y Chart B) Magnetic tape  A) Digital display on strip chart B) Computer punched paper tape  A) Digital display on strip chart B) Computer punched paper tape  Temperature versus time on strip paper chart  Electronic typewriter digital display
SALINITY	Sea Water Sampler 1. Nansen Bottle  a. Volumetric Method (Titration)  b. Conductivity Bridge Salinometer (University of Washington)  Electrical Method 1. Conductivity Cell  a. Foxboro Company  b. Gerfass Bridge	Salinity Accuracy: $\pm 0.02$ part per thousand  Salinity Accuracy: $\pm 0.005$ part per thousand Repeatability: $\pm 0.001$ part per thousand  Accuracy: $\pm 0.1$ part per thousand  Accuracy: $\pm 1.0$ part per thousand (0.1 part per thousand if calibrated before and after use)	Visual observation, chemical analysis, and recording on standard log format  Dial indicators  Circular chart  Dial indicator	Minimized (transistor, modular, etc.) Salinometer (Atlantic Research Corporation under contract to U.S. Navy Hydrographic Office)	Salinity Accuracy: $\pm 0.005$ part per thousand	Dial Indicator
DENSITY	Reference from other measurements (for instance: temperature, salinity, and pressure or depth)			Indirectly - Sound Velocity Meter (National Bureau of Standards; Chesapeake Bay Institute, Johns Hopkins University)	Sound Velocity Range: covers all sound velocities in the medium (oceans) over a temperature range of 1.0 to 40.0 degrees centigrade and depths to 22,500 feet. Accuracy: $\pm 0.1$ feet per second	A) Digital display on electronic counters B) Outputs for electronic computers
DEPTH	Unprotected Mercury Thermometer  Mechanical Pressure Transducer ( Bourdon tube, bellows, helical coil, aneroid, etc.)  Electrostatic Pressure Transducer ("VIBRATION", strain gauge, variable reluctance gauge, etc.)	Probable error of depths: $\pm 15$ feet for depths less than 3,000 feet; at greater depths to about 0.5%  Depth: 0 to 1,500 feet Accuracy: $\pm 15$ feet  Depth: 0 to 1,500 feet Accuracy: $\pm 1$ feet (Accuracy of the transducer is generally limited by the recording apparatus)	Visual observation on thermometer's scale and recording on standard log format  a) Dial indicator b) Paper strip chart c) Electronic recorders (such as magnetic tape)  Same as above	Strain gauge transducer	Depth: Unlimited Accuracy: $\pm 0.1$ per cent of full scale; $\pm 1$ foot in 1,000 feet	A) Visual graphic presentation B) Output recordings compatible for modern day electronic computers

# SUMMARY

OFFICE PROGRAM			METHODS AND SYSTEMS OF OUTSIDE ACTIVITIES	
METHODS UNDER CONSIDERATION	SYSTEMS UNDER CONSIDERATION	DESIGN CRITERIA AND PROBLEMS	METHODS IN DEVELOPMENT	PROPOSED METHODS AND/OR SYSTEMS
SELF-PROPELLED UNDERWATER VEHICLE PORTABLE THERMOCLINE RECORDER SUBMERGED TEMPERATURE BUOY A STANDARD HIGH-SPEED DEEP-TOWED BATHY-THERMOGRAPH	TELEMETRY SELF-CONTAINED RECORDING TEMPERATURE SYNOPTIC NETWORK	SPECIFICATIONS OF SENSORS: 1. Repeatability and Accuracy $\pm 0.01^\circ\text{C}$ 2. Fast response time 3. Durable 4. Watertight 5. Linear output  SPECIFICATIONS OF SYSTEMS: Standardization of output signals compatible to modern day machine tabulation and/or computers	AIR DROPPABLE BATHYTERMOMOGRAPH (Bureau of Weapons)  ELECTRONIC BATHYTERMOPHOTOGRAPH (Scripps Institution of Oceanography; Woods Hole Oceanographic Institution; Naval Research Laboratory; Hytech)	Detection of water motion changes through correlation of temperature and salinity (Farno Wooldridge Corporation)
			INFRARED DEVICE for detecting temperature changes for detection of underwater vehicles (Naval Research Laboratory)	Air or ship-expendable temperature-depth measuring sensor (Minneapolis Honeywell)
			TEMPERATURE PROBE (Scripps Institution of Oceanography)	Continuous recording mechanical bathythermograph (American Cage Division)
				Hand-held radiometer (Barnes Engineering Corporation)
In situ analyzers using conductivity, inductance or capacitance effects  Interferometers and beta absorption techniques  Precision salinometers  Vibrator triggered multiple sea sampler  Servo temperature compensated system	Portable, miniaturized salinometers for submarines utilizing continuous intake system	Sufficient accuracy for use in coastal waters  Reduced size and weight  Portable  Automatic collection of sea samples  Sense ocean salinities over range of 20-40 parts per thousand Accuracy: $\pm 0.001$ part per thousand  Non-polarized electrodes  Stability of the electronics  Ease of calibration and alignment  Effects of dissolved gases and organic matter in sample	Conductivity-Temperature Indicator (Chesapeake Bay Institute; Johns Hopkins University)  Induction-Conductivity-Temperature Indicator (Chesapeake Bay Institute, Johns Hopkins University)  Conductivity Bridge (Woods Hole Oceanographic Institution)  Radio Frequency Salinity Measuring Instrument (Texas Agricultural and Mechanical College, Oceanography Department)  Automatic Chlorinity Titrator (Scripps Institution of Oceanography)  Salinity-Temperature-Depth Recorder (Woods Hole Oceanographic Institution) Temperature-Chlorinity-Depth Recorder (Commonwealth Scientific and Industrial Research Organization - Australia)  Interferometer (USSR)	Airborne salinometer (Changing frequency due to changing salinities)
Beta Particle Counter		Instruments not sensitive to: 1. Gravity 2. Acceleration 3. Dissolved gases 4. Organic matter in sample	Vibrating Rod Densitometer (Woods Hole Oceanographic Institution)  Beta Particle Absorption (Texas Agricultural and Mechanical College)  Swallow Buoy (British; Woods Hole Oceanographic Institution)  Vibrating Reeds and Forks  Index of Refraction	Direct Density Measuring System (Breeze Corporation, Incorporated)
Standard Pressure Transducer	Air droppable sonar-depth transmitter and telemetering system	Pressure transducers that are: 1. Accurate (reproducible) 2. Expendable 3. Adaptable (can be used with arrays of various kinds) 4. One degree higher order of accuracy than presently available	Buoyant Tube (Scripps Institution of Oceanography; Woods Hole Oceanographic Institution; North Pacific Fisheries Exploration and Gear Research)  "Vibrator" (Scripps Institution of Oceanography)  Strain Gauge (Statham manufacture)  Acoustic telemetering depth meter with Buoyant tube (Woods Hole Oceanographic Institution)	"Up-and-Down" Sonar System (Woods Hole Oceanographic Institution)  Optical Differential Pressure Instrument  Semiconductor Transducers  Pressure Sensitive Paints

## U. S. NAVY HYDROGRAPHIC

MEASUREMENT	PRESENT METHOD	OPERATING LIMITS	TYPE OF RECORDING	METHODS IN DEVELOPMENT	OPERATING LIMITS	TYPE OF RECORDING
CURRENT	MECHANICAL CURRENT METER (ROMAN)	SPEED: 0.15 to 2.5 knots Accuracy: $\pm 0.1$ knot DIRECTION: 0 to 360 degrees Accuracy: $\pm 10$ degrees	Speed, direction, and time are recorded manually on standard line. Used for first observations for Roman Current Meter (PRNC-NHO-1501)	SELF-CONTAINED SUBMERGED BUOY WITH SUSPENDED METER	SPEED: 0.2 to 5.0 knots Accuracy: $\pm 0.1$ knot DIRECTION: 0 to 360 degrees Accuracy: $\pm 10$ degrees	Photographic film
	ELECTRO-MECHANICAL CURRENT METER			ELECTROMAGNETIC UNDERWATER LOG (Little Industries under contract to Bureau of Ships)	SPEED: 0.01 to 25.0 knots Accuracy: $\pm 0.1$ knot DIRECTION: Vectors - 4 points Accuracy: $\pm 10$ degrees	Computer punched paper tape and/or magnetic tape
	1. PRICE METER	SPEED: 0.1 to 6.5 knots Accuracy: $\pm 0.1$ knot DIRECTION: None	A) An observer with an earphone records electrical pulses against time B) Output signal placed on a wax impregnated paper tape	MAGNETIC PICK-UP ROTOR ("SAVONIUS ROTOR" - Scripps Institution of Oceanography and Hytech Corporation)	SPEED: 0.05 to 3.5 knots Accuracy: $\pm 0.01$ knot	Magnetic tape and/or oscillographs
	2. ROBERTS METER MOD. 3	SPEED: 0.2 to 7.0 knots Accuracy: $\pm 0.1$ knot DIRECTION: 0 to 360 degrees Accuracy: $\pm 10$ degrees	A) Wax impregnated paper tape B) IBM typewriter C) Observing visually on electronic counters	FM TELEMETERED CURRENT METER (modified from Coast and Geodetic Survey)	Limited by existing current meters	Strip chart and magnetic tape
	3. LOW VELOCITY TYPES					
	a. KITTEN	SPEED: 0.1 to 7.0 knots Accuracy: $\pm 0.1$ knot DIRECTION: 0 to 360 degrees Accuracy: $\pm 10$ degrees	Same as Roberts Meter			
	b. CROUSE-HINDS	SPEED: 0.1 to 7.0 knots Accuracy: $\pm 0.1$ knot DIRECTION: 0 to 360 degrees Accuracy: $\pm 10$ degrees	Same as Roberts Meter			
	c. FRUITT	SPEED: 0.1 to 7.0 knots Accuracy: $\pm 0.1$ knot DIRECTION: 0 to 360 degrees Accuracy: $\pm 10$ degrees	Same as Roberts Meter			
	d. CM-3 JAPANESE	SPEED: 0.2 to 5.0 knots Accuracy: $\pm 0.1$ knot DIRECTION: 0 to 360 degrees Accuracy: $\pm 10$ degrees	Speed and direction are observed on dial indicators			
	GEOMAGNETIC ELECTRO KINETOGRAPH (GERM)	Uncertain	Paper strip chart			
	PHOTOGRAPHIC TYPE (GERMAN PADDLE WHEEL)	SPEED: 0.3 to 3.0 knots Accuracy: $\pm 0.1$ knot DIRECTION: 0 to 360 degrees Accuracy: $\pm 10$ degrees	Photographic film strips			
	PARACHUTE DROGUES	(Speeds and accuracies determined from tow tests by the Hydrographic Office)	The instrument's radar reflector tracked by ship's radar system			
	DRIFT BOTTLE		Bottle label "Return to U.S. Navy Hydrographic Office"			
WAVE MOTION AND DIRECTION	VISUAL SEA SWELL OBSERVATIONS		Standard log format	AIRBORNE SEA-SWELL RECORDER (Contract to Naval Research Laboratory - Bureau of Weapons)		
	BOTTOM PRESSURE INSTRUMENTS					
	1. Wiancko Pressure Measuring System (U.S. Navy Mine Defense Laboratory)	DEPTH: Up to 200 feet Sense changes in water height of 0.1 inch to 80.0 inches	Paper strip chart			
	FLOATING WAVE GAUGE					
	1. Electric Wave Staff	DEPTH: 0 to 20 feet Accuracy: $\pm 0.5$ foot	Paper strip chart			
	FIXED WAVE GAUGE					
	1. Resistance Wire Wave Staff (Research by U.S. Navy Hydrographic Office; development by Atlantic Research Corporation under contract to Hydro)	DEPTH: 0 to 15 feet Accuracy: $\pm 0.2$ foot	Paper strip chart and magnetic tape			
	INVERTED ECHO SOUNDER (Mo Corporation - utilized on sub-marines)	DEPTH: 55 to 100 feet, relative to keel depth Accuracy: $\pm 0.5$ foot	Paper strip chart			
RADIATION	1. Pyrheliometer - solar intensity (Eppley Laboratory)	Intensity Range: 0.25 to 1.000 milli-calories per minute Accuracy: $\pm 1.5$ percent Wavelength Range: 3,000 to 90,000 angstroms Unknown	Paper strip chart			
	2. Radiometer - long wave and solar radiation; diurnal and nocturnal (Seir and Dunkle)		Paper strip chart			

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METHODS UNDER CONSIDERATION	SYSTEMS UNDER CONSIDERATION	DESIGN CRITERIA AND PROBLEMS	METHODS IN DEVELOPMENT	PROPOSED METHODS AND/OR SYSTEMS
PHOTO-ELECTRIC CURRENT METER STRAIN GAUGE VECTOR CURRENT METER SOLID STATE CURRENT METER (THERMISTOR) HOT RESISTANCE WIRE ACOUSTIC FLOW METER	AIR DROPPABLE CURRENT METER SERIES OF BOATS WITH TELE-METERING CAPABILITIES (SYNOPSIS NETWORK) CABLE SUSPENDED CURRENT METERS NOT AFFECTED BY SHIP'S MOTION	<p><b>SPECIFICATIONS FOR SENSOR:</b></p> <ol style="list-style-type: none"> <li>1. Speed Range: 0.1 to 10.0 <math>\text{km}/\text{hr}</math></li> <li>2. Accuracy: <math>\pm 0.1</math> <math>\text{km}/\text{hr}</math> (lower thresholds and accuracies desired for special research projects)</li> <li>3. Resolution: <math>\pm 0.01</math> <math>\text{km}/\text{hr}</math></li> <li>4. Depth range: unlimited</li> <li>5. Simplicity in overall design and operation</li> <li>6. Rugged</li> <li>7. Standardization of output signal range</li> </ol> <p><b>SPECIFICATIONS OF SYSTEMS:</b> Standardization of output signals compatible to modern day machine tabulation and/or computers</p>	<p>ACOUSTIC TRODOLITE (Woods Hole Oceanographic Institution)</p> <p>MAGNETIC FLOW METER (Foxboro Company and Minneapolis Honeywell)</p> <p>PHOTO-ELECTRIC DUCTED METER (Marine Advisors)</p> <p>TWO WAY DOPPLER TO MEASURE WATER FLOW (Westinghouse, Chesapeake Bay Institute)</p> <p>MINIATURE CURRENT FLOW METER (British)</p> <p>SWALLOW BOATS (British and Woods Hole Oceanographic Institution)</p> <p>PROTOTYPE CURRENT METER (Japanese) (Meteorological Research Institute)</p>	Underwater Sonde (Lee Instrument Company) Radioactive Tracers Current Direction Indicator (Airpac Electronics) Air-Expendable Current Measuring Buoy (Spartan Electronics)
30-FOOT ELECTRONIC RESISTANCE WIRE WAVE STAFF WAVE STAFF ACCELEROMETER VIBRATING WIRE PRESSURE DEVICE HIGH FREQUENCY SONIC DEVICE RADAR-TYPE DEVICE	AIRBORNE SEA-SWELL SYSTEMS FLOATING SEA-SWELL SYSTEMS WITH CAPABILITIES FOR SELF-RECORDING OR TELEMETRY ACOUSTIC WAVE-HEIGHT SYSTEMS	<p>Stable reference level</p> <p>Wide range devices</p> <p>Turbulence measuring instruments</p> <p>Wave direction indicators</p> <p>Measure wave periods from 1-30 seconds</p> <p>Must withstand prolonged use in severe environments</p> <p>Wave records compatible to wave and power spectrum analyzers (Naval Ordnance Laboratory - David Taylor Model Basin)</p> <p>Wave records on magnetic tape supplemented by a visual record for monitoring and other special purposes</p>	<p>BOTTOM PRESSURE DEVICES (Naval Ordnance Laboratory; University of California; Scripps Institution of Oceanography; Bureau of Yards and Docks)</p> <p>SHIPBOARD WAVE ACCELEROMETER (British National Institute of Oceanography; Woods Hole Oceanographic Institution)</p> <p>ELECTRONIC SEA-WAVE RECORDER (India)</p> <p>"SPLASHMIX" (David Taylor Model Basin)</p> <p>FLOATING TYPE WAVE RECORDERS (David Taylor Model Basin; Woods Hole Oceanographic Institution)</p> <p>FIXED WAVE GAUGES (Beach Erosion Board; Corps of Engineers; Army)</p> <p>STEREO PHOTOGRAPHY (Naval Research Laboratory)</p> <p>ACOUSTIC WAVE HEIGHT INDICATOR (American Bausch Arm Corporation under contract to Bureau of Ships)</p> <p>MULTI-PRONE WAVE HEIGHT/SLOPE RECORDING SYSTEM (Woods Hole Oceanographic Institution)</p> <p>ACOUSTIC SYSTEM MK 1, NOD 5 (Naval Ordnance Laboratory)</p>	Air Droppable Sea-Swell Buoy (General Electric) Optical Wave Height Sensor (Avion Corporation and Airpac Electronics) Auto-correlation Radar System (Glenn L. Martin Company)
			Vortex Thermometer (Naval Research Laboratory)	

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MEASUREMENT	PRESENT METHOD	OPERATING LIMITS	TYPE OF RECORDING	METHODS IN DEVELOPMENT	OPERATING LIMITS	TYPE OF RECORDING
WATER TRANSPARENCY AND LIGHT ABSORPTION	SUBMARINE PHOTOMETER	DEPTH: Approximately 500 feet	Paper strip chart			
	HYDROPHOTOMETER, MARK 2	DEPTH: 200 feet	Dial indicators			
	SECCMI DISC	DEPTH: 20 feet (maximum)	Visual observations			
	WATER CLARITY METER (Visibility Laboratory, University of California)	DEPTH: 500 feet	Paper strip chart			
MARINE BIOLOGY	Meter or Half-Meter Plankton Samplers	Towing speeds: Not greater than 2.0 knots	Inspecting and counting number and types of specimens and recording on standard log format	Hydro Hi-Speed Plankton Sampler	Towing speeds: 10 to 12 knots	Visual inspection
	Clarke-Baump Plankton Sampler (Woods Hole Oceanographic Institution)	Same as above	Same as above	"Shrimp Net" Trawl	Towing speeds: 15 knots	Same as above
	Midwater Trawl	Same as above	Same as above	Multi-Right Angle Trolling Plate Rack		Same as above
	Hi-Speed Sampler (Scripps Institution of Oceanography)	Towing speeds: 8 to 12 knots	Same as above			
	Hardy Continuous Plankton Recorder (British made by Woods Hole Oceanographic Institution)	Towing speeds: 15 knots	Specimens are sieved on a continuously moving band of silk gauze			
	Convex-Concave Fouling Plates	Plates in the environment from 1 month to 2 years	Inspection of fouled plate			
BOTTOM TOPOGRAPHY AND SEDIMENT STRUCTURE	Deep-Sea Multi-Shot Camera (Type III, Navy Electronics Laboratory)	Depth: Greater than 20,000 feet Number of photographs per operation: Approximately 55	Photographic film	Hydro Plastic Corer	Depth: Unlimited Sediment penetration: 10 feet	Inspection of sediment core, a chemical analysis of sample, and recording on standard log format
	Mechanical Bottom Signalling Device - "The Ball Breaker"	Depth: Unlimited				
	Substrata Acoustic Probe (Marine Seismo-probe)	Depth: 700 feet Sediment penetration: 200 feet	Paper strip chart			
	Precision Depth Recorder (comes from Fathometer Corp.) and AN/UX-2 (Ric)	Depth: Up to 18,000 feet Sediment penetration: 120 feet (extreme maximum)	Paper strip chart			
	Fathometer - Echo Sounder (Model 255B, EDO Corporation)	Depth: 2.5 to 1,500 feet Accuracy: ±1 to 6 feet, depending on depth scale in use Sediment penetration: Undetermined	Paper strip chart			
	Cores 1. Gravity Type a. Rileger	Depth: Unlimited-determined by length of lowering cable used Sediment penetration: 4 feet	Inspection of sediment core, a chemical analysis of sample, and recording on standard log format			
	2. Piston Type a. Kullenburg	Depth: Unlimited Sediment penetration: 6 to 12 feet	Same as above			
	b. Ewing	Depth: Unlimited Sediment penetration: 20 to 60 feet	Same as above			
	Grab Samplers 1. Glassbell Sampler (Navy Electronics Laboratory)	Depth: Unlimited Sediment Penetration: Surface	Same as above			
	2. Mud Sampler	Same as above	Same as above			

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METHODS UNDER CONSIDERATION	SYSTEMS UNDER CONSIDERATION	DESIGN CRITERIA AND PROBLEMS	METHODS IN DEVELOPMENT	PROPOSED METHODS AND/OR SYSTEMS
BOTTOM REFLECTOMETER WATER CLARITY METER WITH AUTOMATIC CALIBRATOR CONTRAST METER LUMINOMETER OPTICAL OCEAN PARTICLE IDENTIFIER OPEN OCEAN CLARITY INSTRUMENT	UNDERWATER UNIT COMPATIBLE TO FUTURE RESEARCH VEHICLES LIKE SHIPS, BOATS, SUBMERGED SELF-PROPELLED VESSELS, ETC. OUTPUT SIGNALS COMPATIBLE FOR MODERN-DAY MACHINE TABULATION	Automatic calibration Base of alignment Determine suspended particles in ocean by 1. Size 2. Number 3. Type Measure attenuation of ambient light with depth Transparency measurement in relatively clear open ocean water Measurement of number of wavelengths Dependable Moderately simple	CONTRAST METER (Edward Street Laboratory, Yale University) DIAL FILTER HYDROPHOTOMETER (Chesapeake Bay Institute, Johns Hopkins University, Office of Naval Research) WATER TRANSPARENCY METER (Oceanographic Institute, Sweden; Woods Hole Oceanographic Institution) SELF-CALIBRATING WATER CLARITY METER (Visibility Laboratory, University of California under contract to Navy Ordnance Test Station, China Lake, California) THI-FILTER HYDROPHOTOMETER GLAZED BATHYPHOTOMETER (Woods Hole Oceanographic Institution)	Detecting and Differentiating Optical Wave-lengths (Trident Company)
Sonic Detection of Sonic Fish Bioluminescence Instrument Benthic Organisms Sampler Photoelectric Luminescence Recorder	Marine Productivity Rating System	Collect specimens from all depths Collect specimens horizontally and vertically Capture large and small specimens Capture the more active swimmers Secure undamaged specimens Record exactly the amount of water sampled and at what depth Sample over long distances Sample several depths simultaneously	Hydrophone Sampler (Narragansett Marine Laboratory under contract to Office of Naval Research) Beam Trawl - modified Agassiz type (Japanese) Isaacs Hi-Speed Sampler	Photometers and/or water clarity meter
Pathometer with bottom reflection coefficient meter Underwater stereo photography Deep water television Ocean-bottom seismograph High speed augers Jet-propelled corers	Multiple sonar arrays	High power transducer Broad-band energy source High repetition rate Short pulse length for thin-bed resolution Cored sediment representative of <i>in situ</i> conditions Improved release mechanism Deeper sediment penetration Non-distortion of sediment sample Adequate sediment sample for laboratory analysis Optimum physical dimensions of piston corers Portable shipboard analysis kit	Bottom reflectivity meter "Smith-Cummins Apparatus" - Acoustic probe Sub-bottom depth recorder (Lamont Geological Observatory, Columbia University) Seismic profiler (Woods Hole Oceanographic Institution) Subsurface Explorer - SUBSURREX (Navy Electronics Laboratory) Precision Graphic Recorder (Alden Electronics; Woods Hole Oceanographic Institution) Sonar Shucker - EMF current repulsion of a non-magnetic disc Stratigraph (EDC Corporation) Variable Depth Sonar - VDS (Bureau of Ships) Marine Sciences Corporation (Socorro Mobil Oil Company, Incorporated) Hydrostatic type corer - "Slurper" (USSR) Piston corer with tripod side legs (geological Institute, University of Tokyo, Japan) SIO Shucker (Scripps Institution of Oceanography)	Multiple sonar arrays Self-contained electrical corer (United States Instruments)

## U. S. NAVY HYDROGRAPHIC

MEASUREMENT	PRESENT METHOD	OPERATING LIMITS	TYPE OF RECORDING	METHODS IN DEVELOPMENT	OPERATING LIMITS	TYPE OF RECORDING
TIDES	Portable Automatic Tide Gage	Sense tide changes to approximately 0.1 foot	Paper Strip Chart		The U. S. Navy Hydrographic Office does not actively participate in any development on tide measuring devices, but utilizes tidal information obtained from Coast and Geodetic Survey.	
GRAVITY	SUBMARINE AND SURFACE SHIP GRAVIMETERS 1. LaCoste and Romberg 2. Askania (Graf), West Germany  GEODETIC (LAND) GRAVIMETERS  1. WORDEN GRAVIMETER RANGE LIMIT: a) Equator to approximately 45° north and south latitude b) About 30° to 90° north and south latitude Accuracy: $\pm 0.1$ milligal  2. NORTH AMERICAN GRAVIMETER TOTAL RANGE: 1,000 milligals (Can be used world-wide by re-setting it.)  3. LACOSTE AND ROMBERG GRAVIMETER		Dial Indicators			
GEOMAGNETIC	VECTOR AIRBORNE MAGNETOMETER Types 2A and 2B (Naval Ordnance Laboratory)	TOTAL FIELD: 23,000 to 78,000 gammas Accuracy: $\pm 0.05\%$ Inclination: $-90^\circ$ to $+90^\circ$ Accuracy: $\pm 0.1^\circ$ Magnetic Heading: $0^\circ$ to $360^\circ$ Accuracy: $\pm 0.1^\circ$ Relative Bearing (Astro): $0^\circ$ to $360^\circ$ Accuracy: $\pm 0.1^\circ$	BASE LINES: Manual Tabulation INCREMENTS: Strip Chart Graphic	1. AIRBORNE FREE NUCLEAR PRECESSION MAGNETOMETER (Varian model V-4310)  2. PHOTOELECTRIC SECANT EC-1000 (AN/AW-1 modified to the EC-1000) to Office's specifications to supplement or replace the Relative Bearing (Astro) position of the Vector Airborne Magnetometer.	TOTAL FIELD: 25,000 to 73,000 gammas Accuracy: $\pm 0.006\% \pm 0.5$ gamma  RELATIVE BEARING (ASTRO): $0^\circ$ to $360^\circ$ Accuracy: $\pm 0.05^\circ$ (design objective) Altitude (Astro): $0^\circ$ to $90^\circ$	BASE LINES: Manual Tabulation INCREMENTS: Strip Chart Graphic  MECHANICAL COUNTERS: Manual Tabulation and Synchronized Data Camera

# SUMMARY

## OFFICE PROGRAM

## METHODS AND SYSTEMS OF OUTSIDE ACTIVITIES

METHODS UNDER CONSIDERATION	SYSTEMS UNDER CONSIDERATION	DESIGN CRITERIA AND PROBLEMS	METHODS IN DEVELOPMENT	PROPOSED METHODS AND/OR SYSTEMS
Standard Pressure Type Tide Gage Air-Droppable (expendable) Tide Device Deep-Ocean Tide Devices	Telemetering Tide - buoy network Transmitting several tide stations to a central collection point Output signals compatible for electronic counters	Accurate determination of a vertical datum Crustal movements Classification of tides effecting different coast lines Accuracies: 0.01 foot Determine parallax and declination cycles Tidal pulsations in deep ocean water Tidal buildup	Precise echo-sounder for tides Mechanical portable tide gage (Coast and Geodetic Survey) Automatic registering tide gage Non-registering tide gage 1. Pressure type 2. Floating type 3. Staff type Pressure Plate Tide Gage (Foxboro Company) Tide-Storm Surge Instrument (Hammar - Dahl Co., Rhode Island; Beach Erosion Board) Digital-type tide gage - portable and/or fixed. (Coast and Geodetic Survey) Bubble-type tide gage - radio transmission (Coast and Geodetic Survey) Telephone transmitted tide gage (standard) network (Coast and Geodetic Survey) Tide Prediction Machine - 36 inputs (Coast and Geodetic Survey)	
Standard ocean gravity meter for all Hydrographic Office survey ships Miniaturized automatic gravimeter for submarines Airborne gravity meter	Gravity recording system compatible to modern-day machine tabulation or computers Comparative test system on new equipment witnessed by the Hydrographic Office, cognizant manufacturer, and an impartial activity like the Coast and Geodetic Survey	Gravimeter specifications: Portable Absolute (no drift) measurement Secondary control points Accurate to 0.1 milligal One year life for platform gyros One minute angular error Low cost (\$25,000) Maintenance Flexibility for ship to submarine and return Minimum maintenance Simplicity in operation A world-wide range to avoid resetting problems Calibration correction over its full range Linear response Gravity calibration ranges Increased improvement of navigational equipment to support gravity measurements	ABSOLUTE GRAVITY METER (National Bureau of Standards) AERBORNE GRAVIMETER (Air Force Cambridge Research Center; LaCoste and Romberg Fairchild Aerial Surveys; Gravity Meter Exploration Company) GRADIOMETER (Lundberg Explorations, Canada) SHALLOW WATER GRAVIMETERS SURFACE SHIP GRAVITY METER (Lamont Geological Observatory, Columbia University) "WORLD-WIDE" METER METERS ON STABLE PLATFORMS	
1. Supporting components to improve and modernize the Vector Attitude Magnetometer, Types 2A and 2B a. Constant voltage current source b. Precision current control c. Mounting base and gimballs	Automatic programming and recording system.	Greater flexibility, economy of effort, and reliability using available components.  Accuracy and reliability under severe environmental conditions Accuracy and ease of operation Rigidity, shock mounting and precise establishment of "rubber line"	1. SACLAY (Overhauser Effect) Magnetometer (Total field) 2. ALKALI VAPOR MAGNETOMETER employing low frequency sweep (non-resonant) (Total Field). 3. METASTABLE HELIUM MAGNETOMETER (Total Field) 4. PORTABLE ELECTRICAL MAGNETOMETER; Survey Grade Magnetometer (Dominion Observatory of Canada) 5. RECORDING FLUORINE MAGNETOMETER; 3-component (Canadian Applied Research Laboratory)	

U. S. NAVY HYDROGRAPHIC					
MEASUREMENT	PRESENT METHOD	OPERATING LIMITS	TYPE OF RECORDING	METHODS IN DEVELOPMENT	OPERATING LIMITS
SEISMIC	MARINE NAVIGATIONAL AID MAGNETOMETER (Varian free nuclear precession magnetometer, model XN-4901)	TOTAL FIELD: 25,000 to 73,000 gammas Accuracy: $\pm 0.003\%$ $\pm 0.5$ gamma	BASE LINES: Manual Tabulation INCREMENTS: Strip Chart Graphic and/or Binary Coded Punched Paper Tape		
LAND MAGNETIC STATIONS; Russia	Field Magnetometer	MAGNETIC DIP: 90° N. to 90° S. $\pm 1'$ MAGNETIC MERIDIAN: 0° to 360° $\pm 1'$ arc TRUE MERIDIAN: 0° to 360° $\pm 1'$ arc LOG MH: $\pm 0.001$ LOG $\frac{H}{M}$ : $\pm 0.001$ M	Manual Tabulation		
POSITIONING	<p>A) Angle and Distance Measuring Instruments</p> <p>1. Angle measuring instruments</p> <p>a. T-2 Theodolite (H. Wild Company, Switzerland)</p> <p>b. T-3 Theodolite</p> <p>c. T-4 Theodolite</p> <p>2. Levels (Wild Models W-II and W-III)</p> <p>3. Distance Measuring Instruments a. Geodimeters</p> <p>1. RASM-2 (AGA, Sweden)</p> <p>b. Tellurimeter (Tellurimeter Ltd., South Africa)</p> <p>B) Electronic Positioning Systems (navigational Aids)</p> <p>1. Hyperbolic Systems</p> <p>a. Loran (Long range accuracy) A</p> <p>2. Ranging Systems</p> <p>a. Shoran (Short range navigation)</p> <p>b. LAMBDA (Decca Navigator Ltd., England)</p>	<p>Angle read to 1 second; estimated to 0.5 second Angulars determined to within 1 second of arc Distance of measuring line 10 to 12 nautical miles</p> <p>Angle read to 0.2 second Distance of measuring line 25 to 30 nautical miles</p> <p>Angle read on horizontal circle to 0.1 second Angle read on vertical circle to 0.2 second</p> <p>Angle read to 1 second; estimated to 0.5 second Angulars determined to within 1 second of arc Distance of measuring line 10 to 12 nautical miles</p> <p>MAXIMUM RANGE: 30 nautical miles Accuracy: 6 feet</p> <p>MAXIMUM RANGE: 38 to 40 nautical miles Accuracy: 20 feet</p> <p>RANGE (useful): Approx- imately 200 nautical miles Accuracy: 15 feet on base line, 400 feet at outer limits of the usable area</p> <p>RANGE: Generally restrict- ed to approximately line- of-sight distances Accuracy: 30 to 50 feet in 40 nautical miles</p> <p>RANGE: Generally restrict- ed to approximately line- of-sight distances Accuracy: 100 to 400 feet, dependent on which end of the range is being used</p>	<p>Visual observations and data recorded on standard log format</p> <p>Same as above</p> <p>Same as above (Time is compared with secondary standards and recorded on paper strip chart)</p> <p>Dial indicators and manually logged</p> <p>Dial indicators and manually logged</p> <p>Dial indicators and data plotted on hyperbolical charts</p> <p>Dial indicators</p> <p>Dial indicators</p>	<p>The U. S. Navy Hydrographic Office does not actively participate in any development on positioning equipment, but generally takes part in calibrating and evaluating new systems.</p>	

# SUMMARY

## OFFICE PROGRAM

## METHODS AND SYSTEMS OF OUTSIDE ACTIVITIES

METHODS UNDER CONSIDERATION	SYSTEMS UNDER CONSIDERATION	DESIGN CRITERIA AND PROBLEMS	METHODS IN DEVELOPMENT	PROPOSED METHODS AND/OR SYSTEMS
2. Three-component magnetic temporal variation recorder		Sensitive detection and recording of orthogonal magnetic temporal variation components related to vertical and known azimuth. Design for portability and remote operation.	6. BALL EFFECT MAGNETOMETER; Component 7. ELECTRON BEAM MAGNETOMETER; Component 8. PROTON PRECESSION MAGNETOMETER for total field and variation vector; $F_z$ changing $D_z$ changing $I_z$ . (Naval Research Laboratory) 9. PROTON PRECESSION MAGNETIC GRADIOMETER (Varian Associates)	
3. Rubidium vapor magnetometer a. Airborne total field measurement (towed detector) b. Shipborne total field measurement (towed detector and deep-sea probe) c. Fixed total field temporal variation measurement		Sensitive and precise detection and recording of total magnetic field and temporal variations. Employ filtering to permit expanded sensitivity in selected pass-bands.	10. RUBIDIUM VAPOR SELF-RESONANT MAGNETOMETER AND GRADIOMETER (Varian Associates)	
4. Precision airborne vector magnetometer system		High precision comparable to station magnetic measurements.		
Ocean-bottom topography Sonar bench marks Inertial navigators Loran transponders Circular method in ranging systems Geometric and astrometric methods	Satellite triangulation system Extended flaring system	Flexibility Portability Improved reliability Greater distance Greater accuracies - 0.25 mile in 5,000 miles	Geodimeter (AGA, Sweden; U.S. Army Engineer Research and Development Laboratory; Highway Department of California) Radio Frequency Distance Measuring Devices: 1. Microdist (Rubit Corporation, California; Highway Department of California) 2. Motorola Corporation Type 3: Airborne Type (U.S. Army Engineer Research and Development Laboratory) Automatic Tracking Theodolite (V. L. E. Gurley Company; U.S. Army Engineer Research and Development Laboratory) Astro-Theodolite (General Mills Corporation under a government contract) Satellite Navigation Loran B (modification on Model A) Loran B (International Telephone and Telegraph under contract to Bureau of Ships; U.S. Coast Guard) Loran C (Sperry-Rand Corporation under contract to Bureau of Weapons; U.S. Coast Guard) Electronic Position Indicator (EPI) (U.S. Coast Guard) Hydrodist (Short-range tellurometers) Rifix (Decca Navigator, England) Hiram (U.S. Air Force) 2-Range Decca (Decca Navigator, England; Bureau of Ships; Western Electric Corporation) Distance Measurement Raydist (Rastings-Raydist, Incorporated; U.S. Coast Guard) Azimuthal Systems (Consel - Europe; Canada; Coast and Geodetic Survey) Composite Systems (Western Electric; Bureau of Ships) SINS (Ship Inertial Navigation System) (Sperry-Rand Corporation; North American Aircraft Company; Bureau of Weapons)	Lunar observations/artificial satellites Geocentric coordinates from lunar and satellite observations Inertial guidance systems



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Appendices, including 5 figs.

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iii. H. O. SP-41

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